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The Mineralogy of Arizona

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BY

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INTRODUCTION

It is well known to students of mineralogy that the greater number of interesting minerals are found at some depth below the surface in regions where the destructive effect of erosion and the decomposing action of meteoric water are not active and hence can be reached only by expensive exploitation rarely undertaken except when compensation is hoped for in the possible discovery of the precious or useful metals. Arizona is attracting considerable attention on account of its unusual mineral resources, and its mountains and cañons are filled with excavations which are evidences of the enthusiasm with which the search is carried on. Thus formations are penetrated and minerals exposed to view which, lacking this incentive, would never have been discovered.

In certain respects many of the minerals in Arizona are sufficiently unusual in their mode of occurrence and in their composition to warrant special attention. The rather common occurrence of vanadium, tungsten and molybdenum, associated with deposits of economic value, has been the subject of frequent mention in the scientific journals. These are of great interest, not only from the variety and beauty of the crystallizations presented, but, containing as they do, elements of considerable rarity, because the chemical and geological conditions which have given rise to them demand investigation. The object of this publication, then, is to give a fairly complete description of Arizona's minerals with some reference to their mode of occurrence, associations and chemical composition. The order of treatment is in accordance with the well known classification of Dana. The elements found as minerals are considered first; then the sulphides and others, as outlined in the following table.

CLASSIFICATION AND ORDER OF TREATMENT

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I. NATIVE ELEMENTS

Diamond, C

Composition and Artificial Production.—The diamond is crystallized carbon not different in its chemical composition from pure charcoal. Because of the simplicity of its composition, attempts have repeatedly been made in chemical laboratories to produce it. The method of investigation usually consists in dissolving carbon in molton iron or similar media, and allowing it to crystallize while cooling. Until recently all such attempts have failed, owing to the habit of carbon to crystallize in the form of graphite rather than in its other possible form, the diamond. Moisson, however, succeeded in producing the diamond by heating iron in which carbon was dissolved to a temperature of 3000 C. by means of an electric furnace, and suddenly cooling the mass by plunging it into cold water. By this simple method a cold solid shell was formed, which on contracting, subjected the remaining liquid mass to enormous pressure. Under these extraordinary conditions a part of the carbon crystallized in the form of diamond. The product, however, was too small and in crystals too imperfect to warrant much hope that by this means diamonds of sufficient size and brilliancy could be produced to serve as gems.[1] These investigations, together with the researches on meteorites described below, sug-

[1] Comptes rendus de l'Académie des Sciences, 116, 218.

gest a possible origin of the gem in nature, the factors in its formation being a solution of carbon in a basic magma and high pressure.

Terrestrial Diamond.—Although diamonds have been found in many of the states, notably in North Carolina, Virginia, Oregon, California and Wisconsin, Arizona has yet to report an authentic discovery of this valuable gem mineral. In 1870, however, a company was organized for the exploitation of diamonds and other gems in Arizona and New Mexico. It is said that 80,000 carats of so-called rubies and many diamonds purporting to have been collected from these fields, were displayed to prospective stock buyers. Expeditions to the locality were made, and in a week's time as many as 6,000 carats of rubies and 1,000 carats of diamonds are said to have been gathered. Finally, Mr. Clarence King, then Director of the United States Geological Survey, made a trip to these famous gem fields, and succeeded in bringing to light the fact that an American had actually purchased in London a large quantity of rough diamonds with which the deposit had been salted; salted, in fact, so thoroughly that an occasional diamond was picked up in this district even several years after the event.[1] The incident is well characterized by Hintze in his Handbuch der Mineralogie as a "grossartige Schwindel."

Diamonds are most frequently associated with peridotites, serpentines and other ultra-basic rocks, or the débris accompanying such rocks, a fact that should be borne in mind by the mineralogist or miner while search-

[1] Kunz: Gems, p. 36.

ing for these gems. The recent discovery of diamonds in Arkansas, where they are found in peridotitic rock material similar to the South African fields, is a good illustration of this very characteristic mode of occurrence. These types of rocks, though not abundant in Arizona, are present in certain localities, and they might well be the subject of special research for these gems as well as other minerals known to occur associated with them.

Meteoric Diamond.—The presence of crystallized carbon or the diamond in meteoric iron was first proved by Jerofejew and Latschnow, in 1888, in their investigations of the meteor which fell in Nowo-Urei, Krasnoslobodsk, Russia, on the 22d day of September, 1886. Since that time the diamond has been found in meteoric iron in widely different localities, but notably, perhaps, in the Cañon Diablo specimens found near Coon Mountain, or Crater Mountain, in the northern part of Arizona. Papers on the subject of diamonds in these meteoric masses have appeared by Foote and Koenig,[1] by Huntington and Kunz, by Friedel,[2] by Cohen, and by others. Moisson, in his researches on the artificial production of the diamond in the electric furnace, directed special attention to the occurrence of this mineral in the Arizona meteorites. Some of the crystals obtained by him measured 0.7 by 0.3 millimeters. They were yellow in tint, of rough surface, and transparent.[3]

[1] Am. Jour. Sci., 1891, 42, 413.

[2] Bul. Soc. Min., Paris, 1892, 15, 285.

[3] Moisson : Le Four Électrique, p. 140.

Graphite, C

So far as the writer knows, pure graphite has not been found in Arizona. A black, graphite-like clay is found in large quantities near Benson, and will be described under Graphitic Clay.

Seams of what appeared to be impure graphite in black carbon shales have frequently been observed, but no analyses have been made.

Sulphur, S

Sulphur has been found in very small quantities in some of the crater cones near Sunset Peak, in the San Francisco mountains near Flagstaff. Abundant silicious sinter occurs here, showing that a solfataric period followed the more active stages of vulcanism. The sinter is frequently of a pure sulphur yellow tint and has been mistaken by many tourists for sulphur.

Arsenic, As

Attention has recently been called to an interesting occurrence of this element in Washington Camp, Santa Cruz County.[1] Here it occurs in reniform masses, sometimes several pounds in weight attached to the walls of a small pocket in dolomitic limestone. The latter is highly metamorphic and crossed by veins carrying lead, copper and zinc minerals. Intrusive rocks are abundant in the district and are considered to be concerned in some way with the mineralization of the limestone. The action especially concerned with the deposition of the arsenic is supposed to be fumerolic.

[1] C. H. Warren: Amer. Jour. Sci., 4th series, 16, 337.

Gold, Au

As is well known, native gold occurs in many localities in Arizona both as placer deposits and vein formations. Nuggets of the value of $400.00 each have been taken from the Weaver placers.[1] Other well known placers are those of Graterville, Cañada del Oro in the Catalina mountains, Linx Creek near Prescott, etc. A description of these deposits, as well as of the gold veins of Arizona, would appear more properly, perhaps, in a publication on mines than in one on mineralogy. A few rather interesting modes of occurrence may, however, be mentioned.

Native Gold in Igneous Rocks.—An unusual occurrence of this kind was recently called to the writers attention by Mr. G. W. Maynard, a mining engineer of New York City. The gold is found in thin paper-like incrustations in the fine cracks of a rhyolitic rock, which occurs on the northeast slopes of the Catalina mountains, near Tucson. The rock is somewhat brecciated in places, the fragments, also rhyolite (felsite), being partially digested by the magma. The rock, when crushed and panned, shows a distinct color of gold, but analyses never give more than a trace of the precious metal. Mr. G. P. Merrill[2] and W. P. Blake[3] have described the occurrence of gold in granite, and Mr. Moericke[4] its occurrence in a trachitic rock. In all of these cases the gold seems to be

[1] W. P. Blake: Rep to Gov., 1899.
[2] Am. Jour. Sci., 4th series, 1, p. 309.
[3] Am. In. Min. Eng., 26, 290.
[4] Tschermaks: Min. u. Pet. Mit., III, 1891.

primary, sometimes embedded and even completely enveloped in crystals of quartz and feldspar. In the rocks of the Catalina mountains it would seem quite probable that the gold is secondary, having been deposited in the minute cracks by percolating solutions. Quite likely the gold originally existed in the eruptive but in such minute quantities that it could be detected only after the concentration described above had taken place. The writer has frequently observed similar superficial mineralization along joint planes, especially in the case of copper where the country rock has become quite deeply stained. These have often led to expensive and useless exploitations.

Gold in Crystallized Calcite.—Some years ago a small sample of vein material was received by the writer from the Vekol mining district which consisted chiefly of white quartz and cleavage masses of calcite. Embedded in the latter were several small grains of gold about two millimeters in diameter. It might at first seem that the gold had been formed by the same processes and at the same time as the calcite. A closer inspection, however, showed that the grains of gold were in reality attached to quartz and were projecting into a cavity, which later became filled with the enclosing calcite.

Gold in Cerussite.—This unusual mode of occurrence has been observed in specimens from Oro Blanco. One large sample, weighing several pounds and consisting almost entirely of cerussite, was found to contain nearly one ounce of gold per ton. The gold was in a very fine-

ly divided state and could rarely be seen even by the aid of a hand lens. The association being so intimate in this case one is inclined to look upon the gold as having been deposited at the same time and under identical conditions as the carbonate, although it is usually held that gold is not deposited from the same media as those which give rise to lead minerals, especially lead minerals occurring in the oxidized zone. Even where lead minerals are found in the same deposit as gold, the gold is usually either in the gangue or in some accessory mineral. This is well illustrated in the ores from the Elkhart mine, near Chloride, Mohave Co., Arizona. The chief minerals found here are quartz gangue, galena and pyrite, and the ore is worked chiefly for its values in gold and silver. Silver is found to accompany the galena and gold the iron pyrite.

Silver, Ag

Native silver has been found in the Silver King mine, Pinal Co., and in small quantities associated with argentiferous ores, in other mines of the State.

Copper, Cu

Native copper is frequently found in the zone of oxide enrichment in many of the copper mines of the State. It is especially abundant at Bisbee, in the Copper Queen mines, the Shattuck, and others, where it occurs in sheets, nodules and aborescent growths associated with cuprite, kaolin, calcite, limonite, and other minerals. It is interesting to note that in the Holbrook shaft, especially in the neighborhood of the 400 ft. level, the ore

lenses contain considerable chalcocite. These have frequently become oxidized only on their margins. This has become a guide to the miners, and when striking native copper after driving through barren ground, they know they are about to reach a rich ore shoot. When they are in ore and strike native copper they believe that they are near the end of the rich deposit. A large sample of native copper presented to the University, by Dr. H. W. Fenner, of Tucson, shows delicate sponge-like forms consisting of aborescent masses altered superficially to malachite. Another interesting mode of occurrence observed in situ by the mining class of the University while on one of its annual trips, was that of delicate mosslike masses containing embedded rhombs of calcite of almost perfect development. In the mines of Cananea, Mexico, the mode of occurrence is somewhat different. Here the native copper is found in thin sheets and slabs between the fracture planes in brecciated quartzite, and is not so often associated with the other enrichment minerals of copper.

Native Copper in Epidote.—Many of the copper deposits of Arizona are in a contact zone associated with garnet, epidote, and other minerals characteristic of contact metamorphism. It is not often, however, that the minerals of copper, and especially native copper, appear in the same hand specimen as the contact minerals mentioned above. Samples showing this intimate association have been received at the University from two distinct localities, one from the northern part of the State,

the exact place unknown, and the other from the Santa Rita mountains, south of Tucson. The two samples were almost identical in appearance. They were made up of hard, compact epidote of the characteristic yellow color, and in places contained as many as forty or fifty brilliant grains of copper to one square inch of surface. These vary in size from a fraction of a millimeter to two or three millimeters in diameter. The epidote from the Santa Rita locality is slightly altered by the infiltration of both calcite and silica. It may be possible that the presence of the copper is due to the same secondary action.

Native Copper in a Trap Rock.—Although this mode of occurrence has been observed only in case of a dike found in Sonora, Mexico, it is considered of sufficient interest at this point to warrant a brief description. The rock is found near Washington Camp, Arizona, only a few hundred feet from the Mexican line. It is quite undecomposed in appearance. Fresh fractures show it to be a dark colored, almost black eruptive, presenting in places the characteristic orphitic structure of the diabases. The rock is crossed by many small fracture planes, along which remarkably slight alteration has taken place. Yet it is along these planes that the copper appears as thin paper-like fillings and aborescent incrustations, giving the surface of the rock as it is broken open a metallic, moss-like appearance. Under the petrographic microscope, the rock is found to be a quite typical diabase, with orphitic structure fairly well developed, with the

exception that the feldspars contain numerous and remarkably large inclusions of the pyroxenes. The latter mineral is but slightly altered to chlorite, while the feldspars are sufficiently fresh to show the characteristic polysynthetic twinning of the plagioclases. The copper appears as small bunches and in thin threads, which sometimes nearly cross the field of the microscope. These are, of course, cross sections of the fracture planes mentioned above. The threads are sometimes not more than 0.02 millimeters in width and several millimeters in length. The copper has evidently been brought in and deposited by solutions which have not materially affected the rock through which they passed. The metal may have been derived from other portions of the dike, or more probably from other mineralized rocks in the vicinity.

Platinum, Pt

Traces of this metal have been reported by the United Geological Survey,[1] in a sample of black sand from near Prescott, and in another sample of the same material from near Columbia. At the University of Arizona several samples of supposed platinum ore have been investigated, but always with negative results.

Iron, Fe.

Native iron is not often found as an original constituent of the earth's crust. It has been observed, however, in nearly every part of the world in the form of meteoric iron. These fragments are simply inter-planetary

[1] Mineral Resources, 1905.

particles which the earth picks up during its journey through space. These particles have been seen to strike the earth and having been examined before they have had time to become cold, there is no doubt as to their immediate origin. It is claimed[1] that during every 24 hours the earth encounters many millions of these fragments, and, were it not for the protecting influence of our atmosphere, the vegetation and animal life would soon be destroyed owing to the continual impact of these minute projectiles. The atmosphere serves as a protecting medium through which these minute bodies are unable to pass without becoming thoroughly disintegrated into a fine dust, due to the high temperature caused by friction. Though very few of them ever reach the earth in a compact form, yet the weight of our planet is yearly increasing at the rate of a few tons as a result of these additions. Indeed, it is even believed by many geologists that our planet and the other heavenly bodies owe their origin to this source rather than to a central molten or gaseous mass which by centrifugal action has successively thrown off masses that have developed into planets, moons, etc.

The Tuscon Meteorites.—Two important masses of meteoric iron have been discovered in the vicinity of Tucson, but thoroughly reliable data as to the exact point where they fell seem to be lacking. The majority of the reports mention the Santa Rita mountains, south of Tucson, as the original locality, while a few authorities refer to the fall as having taken place in the "Santa

[1] Todd: New Astronomy, p. 412.

Catarina'' mountains north of Tucson. The fact that Mexico is sometimes mentioned is to be expected since at that time Tucson and vicinity were a part of that country.

According to Mr. L. Fletcher[1] the attention of the scientific world was first called to these meteorites through

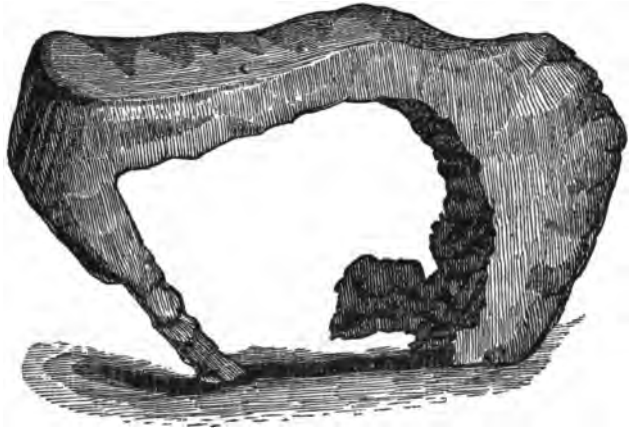

Fig. 1.—The Tucson Ring Meteorite as originally seen in a blacksmith shop in Tucson, where it was employed as an anvil.
(Drawn by Geo. Nishihara from an old wood cut in Bartlett's Explorations, Vol. II, 1854.)

the verbal report of the entomologist, Dr. J. L. LeConte of Philadelphia, at a meeting of the American Association for the Advancement of Science held at Albany in August, 1851. He reported that "while passing through the village of Tucson in the proceeding February, he had observed two large pieces of meteoric iron used by the

[1] The Meteoric Iron of Tucson, Mineralogical Magazine, 9, No. 41, p. 16.

blacksmiths of the town as anvils." The blacksmiths were reported as having been very persistent in not allowing him to chip off fragments for further examination stating that in a certain cañon in the immediate vicinity the fragments were so abundant that many samples could easily be obtained.

In 1854, Professor Shepard[1] gave a brief account of these meteorites, in which he states that according to informations furnished him, they were found in a cañon of the Santa Rita mountains, about 25 or 30 miles south of Tucson. Both were reported as being used as anvils, and one was described as being of a peculiar annular form. About this time also, samples were analyzed by Professor Lawrence Smith[2] and others.

In 1857, Dr. Irwin, Surgeon of the United States Army, found the ring meteorite in one of the streets of Tucson and took possession of it with the intention of placing it in the Smithsonian Institution. It was started on its journey in 1860, and after traveling to Guaymas, Mexico, then to San Francisco, finally reached Washington in 1863, by way of the Isthmus of Panama. Dr. Irwin states that it was considered by the inhabitants of Tucson at that time to have come from the "Catarina" mountains, and further, that it was believed a meteoric shower had taken place there about 200 years ago.[3] It would seem, however, as explained by Mr. Fletcher, that the term "Catarina" was loosely applied, and that Dr. Irwin was thus misinformed as to the real locality.

[1] Am. Jour. Sci., 2d series, 18, p. 369.
[2] Am. Jour. Sci., 2d series, 19, p. 161.
[3] Smithsonian Report, 1863, and Fletcher: Min. Mag., 9, No. 41.

The dimensions of the annular meteorite, or Irwin Iron, as it is sometimes called, still to be found in the Museum at Washington, are given by Whitney, as follows:

Greatest exterior diameter	49 in.
Least exterior diameter	38 in.
Greatest width of central opening	26½ in.
Least width of central opening	23 in.
Greatest thickness at right angles to plane of ring	10 in.
Width of thickest part of ring	17½ in.
Width of narrowest part	2¾ in.
Weight	1,400 lbs.

This fragment is further known as the Tucson Meteorite, the Signet, the Ring Meteorite, the Ainsa, the Muchacho, etc.

The other fragment from Tucson was of the shape of an elongated flattened slab. Its length was 49 inches, average breadth 18 inches, and varying in thickness from 2 to 5 inches. Its weight was determined to be 632 lbs.[1] It was taken possession of by Gen. Carleton and sent to San Francisco. Hence it is known in Mineralogical literature as the Carleton Meteorite.

As a result of the investigations on polished surfaces of these two meteoric masses, it is generally believed that they were portions of the same mass, or at least both were members of the same meteoric shower.

The chemical composition is illustrated by the following analyses:[2]

[1] Proc. Cal. Ac. Nat. Sci., 1863, 3, pt. 1, p. 49.
[2] Quoted from Min. Mag., 9, No. 41.

	Smith Per cent.	Genth Per cent.	Brush Per cent.
Fe	85.54	83.47	81.65
Ni	8.55	9.44	9.17
Co	0.61	0.42	0.44
Cu	0.03	0.008	0.08
P	0.12	0.10	0.49
Al_2O_3	Trace	Trace	Trace
CaO	—	0.46	1.16
MgO	2.04	2.59	2.43
Cr_2O_3	0.21	—	—
SiO_2	3.02	2.89	2.63

From these analyses it appears that the meteorites are mostly nickel iron, with small quantities of olivine, schreibersite and chromite.

An excellent model of the ring meteorite has recently (July, 1907), been received from Washington, and can be seen at the Museum of the University of Arizona.

Cañon Diablo Iron.—One of the most famous occurrences of meteoric iron in the world is that of the Cañon Diablo iron, found in the immediate vicinity of a slight elevation, variously known as Crater Mountain, Coon Butte, and Meteor Mountain. It is located in the plateau region of Arizona, about twelve miles from the Santa Fe station, known as Cañon Diablo, and thirty-five miles from Flagstaff. The iron is found in fragments scattered on the surface of the ground in sizes varying from that of a bean to masses weighing over one hundred pounds. In all it is said that nearly twenty tons of the material have been gathered and distributed to various museums and private collections in all parts of the world. Occasionally, as many as thirty fragments may be picked

up by one person in a single day. They are especially easy to find immediately after a rain, for then the loose dirt is washed away from the fragments, rendering them more easily visible. The writer visited the locality in 1906, and a search of twenty minutes only was necessary in order to secure a specimen about two inches in length. At the station of Cañon Diablo there were nine large fragments awaiting shipment, weighing from 75 to 150 lbs. each, besides several large boxes containing smaller pieces.

The locality is especially interesting to the geologist, not only on account of the meteoric masses found there, but because of the interesting question as to the origin of the elevation apparently so intimately connected with them. The mountain or hill contains on its summit a well defined depression or crater which has a maximum depth of 600 feet, and a width of 3,500 feet. The walls of the crater, which are quite precipitous in places, are formed by the same strata of sandstone and limestone as those which make up the floor of the plateau. These are tilted and slope away from the cavity, just as one would expect, had the strata been uplifted by some great force acting from below, followed by a collapse of the central mass. There is, however, an entire absence of fused material or volcanic ejectamenta, and no evidence of metamorphism of an igneous character having taken place within a radius of twelve miles. In this respect, the crater is unlike those usually found in a volcanic region. This fact, together with the extraordinary occurrence of meteoric

iron, has led to the supposition by many that the depression was not caused by volcanic action, but by the impact of an immense meteor nearly one-half mile in diameter, which on striking the earth buried itself and formed upturned edges very much as when a bullet falls into soft mud. Others look upon the phenomenon as having been caused by a volcanic explosion which lacked energy sufficient to bring the fused mass to the surface. The explosion was followed, it is supposed, by a complete cessation of vulcanism. This seems to be the better explanation, since it can easily be seen that such an explosion might occur on the border of a region of such extreme volcanic activity as was able to produce the most lofty mountain in Arizona as well as more than a hundred small cinder cones.[1] Dr. Chamberlin of Chicago University looks upon the formation as having been produced by an explosion, due to the vaporization of underground water, brought about by the near approach of molten rock.

Further, there seems to be some doubt on the part of some regarding the meteoric origin of the iron fragments. Dr. Karl Hintze, in his Handbuch der Mineralogie, refers to the Cañon Diablo irons as possibly of terrestrial origin ("terrestrisch vielleicht"). H. Moissan also makes the statement, "Ce fer de Cañon Diablo a été regardé par certains géologues comme une météorite, et par d'autres comme

[1] Coon Mountain and its Crater, D. M. Barringer: Proc. Ac. Nat. Sc., Dec., 1905; Coon Butte, Arizona, B. C. Tilgham; *Ibid*, Coon Mountain Crater, F. N. Guild: Science, 26, p. 24.

un fer terrestre analogue au fer d'Ovifak decouvert au Groenland par Nordenskiold." [1]

The composition of the iron, as shown by the following analyses made by H. Moisson, of Paris, varies greatly in different parts of the same fragment.

	1	2	3	4
	Per cent.	Per cent.	Per cent.	Per cent.
Iron	91.12	95.06	91.09	92.08
Nickel	3.07	5.07	1.08	7.05

Small quantities of silica, magnesia and phosphorus are also reported.

The Weaver Meteorite.—This large meteoric fragment was found in the Weaver mountains, near Wickenberg, Maricopa Co., in 1898. It is of especial interest on account of its high percentage of nickel and cobalt and its uniformity of texture, etching solutions failing to bring out any very characteristic figures. The locality in which it was found has yielded but one fragment of rounded outline, weighing about eighty pounds. Two analyses of this meteorite have been made in the writer's laboratory by Mr. W. B. Alexander and Mr. F. Hawley. The results are shown in the table below.

	Alexander	Hawley
Iron	79.60	81.81
Nickel	18.80	16.63
Cobalt	1.60	1.18
Carbon, manganese, and phosphorus	Traces	Traces
Specific gravity	7.9818	7.987

The meteorite was furthur investigated spectroscopically for helium, but with negative results.

[1] Traité de Chimie Mineral, Vol. 2, p. 192.

II. SULPHIDES, ARSENIDES, ETC.

Tetradymite, $Bi_2(Te,S)_3$

This is a soft, steel-gray mineral consisting of bismuth, sulphur and tellurium. It has been found in small quantities in the Montgomery Mine.[1] It also occcurs in quartz associated with pyrite near Bradshaw City, Yavapai Co., where it is found slightly altered to a brownish decomposition product, probably Montanite, the bismuth tellurate.[2] This mineral frequently contains gold, and is often associated with that metal in the telluride ores of Colorado and California.

Molybdenite, MoS_2

This is a soft mineral, closely resembling graphite in its general appearance. It contains sulphur and the semi-metal molybdenum. The mineral seems to be quite widely distributed in Arizona, where it is frequently found as an accessory in many of the copper, lead and silver deposits. In the Morenci fissure vein, it occurs in primary association with pyrite, chalcopyrite and zinc blende. It is also present in the ordinary smelting ore of the district, as shown by chemical analysis.[3]

In the Santa Rita mountains, 30 miles south of Tucson, it is found in the form of small foliated aggre-

[1] Dana: Text Book of Mineralogy, p. 285.

[2] Genth: Am. Jour. Sci., 3d series, 40, p. 114.

[3] Lindgren: U. S. G. S., PP. No. 43, p. 107.

gates in pure milky quartz, where it alters to molybdite, or the hydrous ferric molybdate.[1]

In the Silver Bell district, northwest of Tucson, it occurs in large masses, sometimes of three or four pounds weight, consisting of crystalline aggregates, and associated in the same hand specimen, with quartz, galena, pyrite and chalcopyrite. It has further been observed associated with secondary sulphides of copper in the mines at Johnson, near Cochise.

Domeykite, Cu_3As

This is a rare arsenide of copper usually presenting a tin-white lustre, easily tarnishing to a dull bronze. It is very tough and somewhat malleable under the hammer. Good specimens of this mineral have been received at the University of Arizona from Cochise County, but no data regarding the associations and mode of occurrence have been obtained.

Argentite, Silver Glance, Ag_2S

This is a dark lead-gray mineral resembling copper glance but easily distinguished from it by its being more easily cut with a knife. It has been reported from the Silver King mine, and is occasionally met with as an accessory in other metalliferous deposits of the State. It is further a quite constant constituent in argentiferous galena but is so intimately mixed with it as to escape observation.

[1] Guild : Am. Jour. Sci., 23, p. 455.

Hessite, Ag_2Te

This is a rare telluride of silver with nearly always some gold. It has been reported from the West Side mine, Tombstone.[1]

Galena, Lead Glance, PbS

This well known mineral is widely distributed in the State, as is shown by the official reports on the production of lead from the different counties. In all about five millions of pounds of the metal were produced in 1905, the greater portion of which was obtained from this mineral. The following counties were represented: Cochise, Graham, Mohave, Pima, Pinal, Santa Cruz, Yavapai and Yuma.[2] The frequent occurrence of this mineral with gold has been mentioned by W. P. Blake.[3] It is frequently found associated with the oxidized products of lead such as anglesite, cerussite, etc., and also with wulfenite, vanadinite, decloizite, etc. The localities and different modes of occurrence are too numerous to mention.

Chalcocite, Copper Glance, Cu_2S

This also is a well known mineral usually found in the zone of secondary sulphide enrichment where percolating copper solutions have come in contact with lean sulphides. It is especially abundant in the Clifton-Morenci district where it is found in disseminated grains and seams in altered porphyries. It is not a primary mineral here as

[1] Hintze: Mineralogie, p. 453.
[2] Mineral Resources, 1905. p. 138.
[3] Rep. to Gov. of Ariz., 1899, p. 105.

supposed by some, but has been formed by the replacement processes taken place between grains of pyrite or chalcopyrite and descending copper solutions.[1]

In the Copper Queen mine at Bisbee it is only occasionally found, where it is described as an envelope on pyrite showing the first stages of a secondary enrichment process.[2]

Stromeyerite, Ag_2S, Cu_2S.

This mineral can hardly be distinguished from copper glance except by chemical analysis. The essential difference consists in the large percentage of silver. It has been observed in the Heintzelman mine,[3] and in the Silver King mine, Pinal Co.

Sphalerite, ZnS.

This mineral is a sulphide of zinc and varies in color from yellow and almost white, through orange tints to black. When pure, it has a characteristic resin-like luster. The darker varieties owe their color to the sulphide of iron, which is present as an impurity. These dark modifications are frequently called by the miners black jack or mock lead; the purer samples are referred to as rosin jack.

Sphalerite has been frequently found as an accessory ore in many of the mines of the State, associated with argentiferous galena, pyrite and chalcopyrite. It has been noted below the zone of secondary enrichment in the Clifton-Morenci district, disseminated in hard

[1] Lindgren: U. S. G. S., PP. No. 43.
[2] U. G. S., PP. No. 21, p. 128.
[3] Dana: Text Book of Mineralogy, p. 290.

limestone and metamorphic rock.[1] It is found in the silver-lead prospects in the San Xavier district, associated with galena and other sulphides. Small quantities have been reported from the copper deposits of the Holbrook and Gardiner shafts,[2] Bisbee. In the Silver King it has been observed as occurring in light sea-green masses, associated with threads of native silver, which sometimes cement the cleavage masses together.[3] It further occurs below oxidized gold ores in the Montana mine of the Oro Blanco district, Santa Cruz Co. The disastrous effect of passing from free-milling gold or silver ores into these basic sulphides is well known.

Zinc of commercial importance has been produced by the Copper King Mines Co., operating in the Tiger district of Yavapai County.[4]

Alabandite, MnS

This rare sulphide is quite abundant in the Lucky Cuss mine at Tombstone; it is usually associated with manganiferous limestone, in both massive forms and specimens possessing good cubic cleavage. It is dull black in color and can easily be recognized from the fact that it gives a dark green streak or powder.

Cinnabar, HgS

The red sulphide of mercury is found in Yuma Co., on the properties of the Colonial Mining Co., 14 miles from Ehrenberg. The ore is said to average about 1½ per

[1] Lindgren: U. S. G. S., PP. No. 43.
[2] Ransome: U. S. G. S., PP. No. 21.
[3] W. P. Blake: Rep. to Gov., 1899.
[4] Min. Res. of the U. S., 1905.

cent. of mercury. The same mineral has also been reported from Yavapai County.[1]

Covellite, CuS

This is an indigo blue sulphide of copper, frequently met with in the Butte mining district, Montana, but very rare elsewhere. It has never been found in good specimens in Arizona, and, in fact, has been noted only in the Ryerson and Montezuma mines in the Clifton-Morenci districts.[2]

Bornite, $3Cu_2S.Fe_2S_3$

This beautiful sulphide of copper and iron can easily be recognized from its striking iridescent tarnish, for which reason it is frequently called variegated copper ore, or peacock ore. The colors vary in the same hand specimen from golden yellow and greenish tints to rich brown and purple. It is nearly always associated with pyrite and the various sulphides of copper.

Bornite is frequently met with in the zone of sulphide enrichment in the Bisbee district and in other copper deposits of the State.

Chalcopyrite, $Cu_2S.Fe_2S_3$

This mineral is known as copper pyrites and can be distinguished from iron pyrites which it closely resembles in its inferior hardness and usually by its duller and more brass-like luster. It occurs in the Copper Queen mine, especially in the lower levels where frequently large bodies are encountered, is less abundant in the Clifton-

[1] Min. Res. of U. S., 1905, p. 398.

[2] Lindgren: U. S. G. S., PP. No. 43.

Morenci district, but constitutes the chief ore in the Jerome, Silver Bell, Twin Buttes, Helvetia and other properties.

Chalcopyrite is probably the mineral in which the copper in many, if not all, of the mines of the State originally existed. It was probably mixed with large proportions of iron pyrites, and might in most cases more appropriately be called cuperiferous iron pyrites. The other minerals have been derived from it by what is known as metasomatic or replacement processes. This goes on very much as follows: The lean sulphide, chalcopyrite or, as suggested above, iron pyrites which contain a small amount of this mineral, on being exposed to the action of air and water, becomes oxidized, setting free among other constituents copper sulphate, which is soluble in water. This solution descends, and coming in contact with the lean sulphides below, a replacement takes place by which copper is deposited in the molecule and iron removed.[1] The deposit is then called an enrichment zone, and such sulphides as bornite, chalcocite, etc., result.

Pyrite, FeS_2

This mineral is so well known on account of its wide distribution that no extended account of its occurrence in Arizona is necessary. It is found as a microscopic accessory mineral in many of the igneous rocks, especially the basic dikes, and as an association in the copper, lead and other metalliferous deposits, including gold bearing

[1] See Chalcocite, where a first stage of this process is mentioned.

veins. In the latter case it is not unusually present near the surface, having been oxidized to limonite or hematite, thus giving the rock a rusty honey-combed appearance. This part of the vein material is called "free-milling," since the pyrite which originally held the gold enclosed in its firm crystalline structure, has become disintegrated, setting "free" the gold which can then be easily extracted by well known metallurgical processes.

Schreibersite, $(Fe, Ni, Co)_3P$

The mineral is a phosphide of iron with some nickel and cobalt. It occurs only in meteorites, and has been reported from the Cañon Diablo irons.[1]

Cobaltite, CoAsS

Cobalt ores, presumably of economic value, have recently been discovered in the vicinity of Jerome. The minerals have not been thoroughly investigated yet, but cobaltite, associated with erythrite, or cobalt bloom, has been positively identified.[2]

Cohenite, Fe_3C

As a mineral, this compound has been found only in meteoric iron. It is a carbide of iron, as the formula given above indicates, and analyses from material isolated from the Cañon Diablo irons, have been reported by Derby.[3]

[1] Derby: Am. Jour. Sci., 1895, 49, 107.
[2] See Erythrite.
[3] Am. Jour. Sci., 1895, 49, 106.

III. SULPHO-SALTS, SULPHARSENITES, ETC.

Bournonite, $(Pb, Cu_2)_3S.Sb_2S_3$

This rather rare mineral has been described by Professor W. P. Blake as associated with pyrite, sphalerite and galena at the Boggs mine, in the Big Bug district.[1] It is a soft, easily fusible dark steel-gray mineral, possessing the chemical composition of a sulphantimonate of lead and copper.

Tetrahedrite, or Gray Copper, $Cu_8Sb_2S_7$

This is a sulphantimonite of copper with varying amounts of the metal replaced by silver, lead, zinc, etc. It more often accompanies silver ores than copper. In Arizona it occurs in the Heintzelman mine and the Silver King, Pinal Co., where assays have run as high as 3,000 ounces silver to the ton.[2]

Pyrargyrite and Proustite, or Ruby Silver Ores Ag_3SbS_3, and Ag_3AsS_3

These rare minerals are the sulphantimonites and sulpharsenites of silver. They have occasionally been met with accompanying other silver ores in many of the ore deposits of the State. (Dana.) When first taken from the mine they possess a beautiful pure ruby color. Unfortunately, however, on exposure to light, they

[1] Am. Jour. Sci., 3d series, 39, p. 45.

[2] W. P. Blake: Report of Ter. Geologist, 1909.

darken and finally become dull black. The beautiful masses from Mexico, preserved in the British Museum, have kept their ruby aspect, having been enclosed in black boxes.

Polybasite, Ag_9SbS_6

This is another rare sulphantimonite of silver, differing from ruby silver, in containing a larger percentage of silver. It has been observed in the Silver King mine. (Dana.)

IV. CHLORIDES, FLUORIDES, BROMIDES, ETC.

Halite, Common Salt, NaCl

This mineral is found dissolved in the water of all streams, springs and underground sources, but ordinarily in such small quantities as to be hardly perceptible except by chemical analysis. It has been found in beautiful transparent masses associated with thenardite, mirabilite and glauberite in the Verde Valley, Yavapai Co., where it appears in irregular deposits in the more abundant sulphates mentioned above. The deposit has resulted from the evaporation of an inland sea or lake.[1] This mineral is further found in salt springs in the upper Salt River Valley.

Cerargyrite, or Horn Silver, AgCl

Horn silver, the miner's name for the chloride and bromo-chloride of silver, can be easily recognized from its waxy appearance, and from the fact that it can be cut with a knife into thin shavings which do not fall apart. It has been frequently observed in the zone of oxidation in many of the silver deposits of the State. It has been reported in the following districts: Tyndall, Santa Cruz Co., Cerro Colorado, Black Warrior and others.

Embolite, Ag(Cl, Br)

This mineral is very similar to the one mentioned above, usually occurring in greenish waxy grains, disseminated

[1] W. P. Blake: Am. Jour. Sci., 3d series, 39, p. 44.

through the vein material. It is especially abundant in the Pearce mining district.

Iodobromite, Ag(Br, I)

This mineral resembles embolite in chemical composition, but has its chlorine replaced by iodine. The mineral is extremely rare, but has been reported from the Hechman mine, near Globe, by Professor W. P. Blake.[1] It appears as a bright yellow to pale greenish thin incrustation in veins of quartz and calcite.

Iodyrite, AgI

This is another very rare mineral of silver appearing in almost identical forms with the proceeding. It has been found in the Cerro Colorado mines.

Fluorite, or Fluospar, $CaFl_2$

Fluospar is a well known mineral, occurring in a great variety of colors, purple, green, pink and white being the most common. It is easily recognized by its hardness and octahedral cleavage, breaking up into small pieces with triangular surfaces. It is a quite common gangue mineral in metalliferous deposits, especially found associated with lead ores. In the mines of the Silver Bell district, it occurs in green cubes with barite, galena and chalcopyrite. In the Castle Dome district north of Yuma, it is found associated with galena, vanadinite, and minerals of silver. In the Dragoon mountains it is found in small quantities in very acid pegmatites associated with huebnerite. It has also been observed in the coarse unmineralized gran-

[1] Am. Jour. Sci., 4th series, 19, p. 230.

ites at the Laguna dam on the Colorado river. Small quantities of this mineral have been produced commercially in Arizona and have sold at prices as high as $11.50 per ton.[1]

Atacamite, $Cu_2Cl(OH)_3$

This mineral which is a rare hydrous chloride of copper has been found only in very small quantities in the United Verde mine, at Jerome, and in the Heintzelmann mine. A similar mineral called Footeite has been described from the Copper Queen mines at Bisbee. (Koenig).

[1] Min. Res., 1903.

quiet water, either lake or ocean. A snow white deposit of this material, occurring in the San Pedro Valley, and associated with fine volcanic ash, has been described by Professor W. P. Blake.[1] Deposits of the same material are also described in the Bradshaw folio of the United States Geological Survey.

Petrified Wood.—This form of silica or quartz is very abundant in Arizona, whose specimens are justly prized by museums and private collectors in all parts of the world. The material is especially abundant in the region of the Grand Cañon and extending southward along the Colorado river to Yuma. The petrifaction sometimes takes the form of impure silicious matter, in which the exact form and structure of the wood is preserved, but not in very pleasing tints. At other times the silicification is in the form of chalcedony, jasper, agate, etc., giving rise to very striking and beautiful specimens. It is remarkable that all these brilliant tints are sometimes mingled in the same piece. A section of a large log showing these variegated tints, weighing over 15 tons, has been polished and deposited in the Museum of Natural History in Paris. The most highly prized specimens are found in the vicinity of Holbrook and Adamana, where many square miles are literally covered with petrified logs, branches and small broken fragments of bright colors. These have been highly prized by the Indians on account of their hardness and color, and may be found with other Indian relics in various parts of the southwest.

[1] Am. In. Min. Eng., 33, 1903, 38.

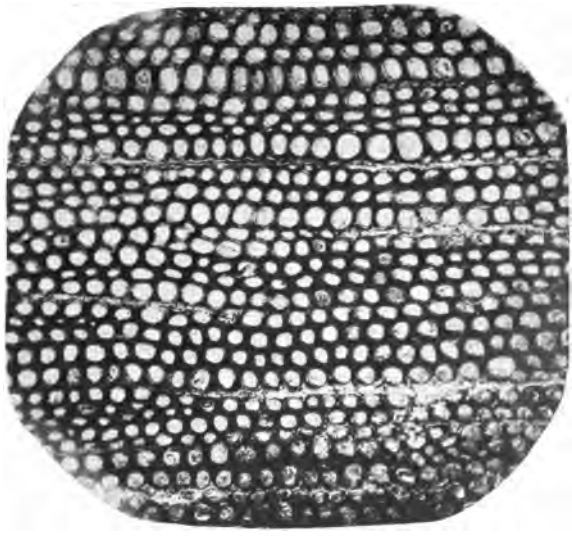

Fig. 2.

A microscopic section of petrified wood, showing the original cell structure.

Geologically the petrified wood of Arizona is supposed to occur in the middle Triassic beds called by Powell the Shinarup group and possessing a thickness of about 1600 feet. The petrified wood is found throughout the entire thickness.

Theory of Petrifaction. — Petrifaction takes place through well known processes of chemistry, by which the molecules of a substance are removed one by one and the molecules of another material deposited in their places. It may be likened to a house originally built of brick in which each brick is carefully removed one by one and a block of marble put in its place until the entire house is changed to marble, yet the shape of the original structure during the whole process in maintained. Thus when a forest becomes buried and subjected to the action of silicious waters, usually hot, a particle of wood decays and a molecule of silica is moulded into its place, the process being carried on with such delicacy that the cells, annular rings, bark, knots and other characteristic features are accurately preserved in stone. How completely and delicately this replacement process has progressed may be seen by the accompanying cut which is a reproduction of a photomicrograph of a thin section taken across the grain. Replacement processes of this nature are well known in mineralogy and in fact are the chief agencies at work in producing ore deposits of sufficient enrichment to be of economic value. (See Chalcocite, p. 25.)

Jasper.—Jasper occurs in a variety of colors and differs from chalcedony in being more opaque and less pure.

The common color is red, and in this shade it is frequently found in pebbles in the streams and in angular fragments on the mesas and in the mountains of the State. In the Petrified Forest, as described above, it is abundant as jasperized wood.

Chrysophase.—Blue and bluish green copper-stained chalcedony has been found in abundance near Globe. "The mineral occurs in small stringers in the Keystone copper mine in that district. The copper ore of this mine is said to be principally chrysocolla or silicate ore. The chalcedony varies in color from bright to pale blue, bluish green, and nearly apple-green, and is more or less translucent. In some places the color occurs in curved layers and varies in intensity, thus bringing out the mammillary structure of chalcedony in peculiar wavy markings. In other places the color approaches that of chrysoprase, or resembles that seen in certain artificially colored chalcedony. Mr. Wightman reports a sale of probably 200 pounds of selected material during 1907 by the miners at Globe. After cutting, this blue chrysoprase brings locally from $3.00 to $10.00 a piece for the best grades."[1]

Flint and Chert.—These are still less pure varieties of silica. They are found as pebbles in the streams, as irregular nodules in limestone, especially in the Aubrey limestone in the Grand Cañon region, and in various other forms.

Amethyst, or amethystine quartz is clear quartz col-

[1] Min. Res., U. S. G. S., 1907, p. 802.

ored purple by traces of manganese. It is sometimes met with in the quartz veins of the State, but in such quality as to make it desirable only as museum specimens. Mr. Kunz has described it as occurring in cavities in the petrified wood of Arizona.[1]

In the McConnico district it is found in precambrian rocks, sometimes in samples of great beauty. One crystal is reported to have been sold to Tiffany, of New York City, for $59.00.[2]

Opal, SiO_2, H_2O

Common opal is similar to chalcedony in composition and appearance, but is uncrystallized and contains a varying amount of water. The precious varieties are not found in Arizona. Semi-opal and the clear variety, hyalite, are occasionally found associated with other modifications of silica. Kunz has mentioned hyalite in Yavapai County.

Cuprite, Cu_2O

The red oxide of copper or cuprite, occurs in massive varieties, resembling hematite, in crystalline modifications in the form of cubes, octahedrons and dodecahedrons, and in capillary incrustations of vivid red. This latter variety is sometimes known as plush copper ore and chalcotrichite, and the transparent variety as ruby copper. Ruby copper forms beautiful specimens when first taken from the mine but they soon become dulled

[1] Gems, p. 116.
[2] U. S. G. S., Min. Res., 1908.

on exposure to light. Plush copper which is more brilliant red is hardly effected by sunlight. All of the varieties mentioned above are frequently met with in Arizona and are especially abundant in the Copper Queen mines at Bisbee and in the Clifton-Morenci district. They are associated with native copper, hematite, limonite, chrysocolla and the other secondary ores of copper. Very pleasing museum specimens are obtained from the Globe mines which consist of massive dark brown cuprite in which are little veinlets and irregular spots of delicate blue chrysocolla.

Tenorite, CuO

This is a somewhat rare mineral and is known as black oxide of copper. It is found in a pulverulent condition mingled with manganese dioxide and associated with other oxidized material in the Copper Queen mines. It is thought to be still forming in the caverns there as the mineral is frequently found covering the floor of cavities where it has dropped from above.[1]

Ice, H_2O

Except on high mountains and in the northern part of the State this mineral in the solid or crystallized condition is rare in Arizona. On the northern slopes of the San Francisco mountains it is sometimes found even in summer months in the well-known form of snow. In the southern portion, the high mountain ranges are frequently covered with it during the winter, and in the valleys

[1] Ransome: U. S. G. S., PP. No. 21, p. 128,

it is well known as frost, and as thin coverings on water occasionally seen in the early morning.

Ice Caves.—In the vicinity of Flagstaff there are numerous small caves found in both basaltic and limestone rocks. A few of these have been known to contain ice throughout the year. It is the custom of picnic parties to visit these localities, well supplied with cream and other dainties, which are then well frozen by the ice thus prepared and stored by nature. The writer visited one of these caves in the summer of 1906. It was located on the black lava flow at the base of Sunset Peak where the streams of lava had evidently cooled, forming a solid crust of basalt which, due to further movement of the mass beneath, had broken up the lava crust into a heterogeneous mass of angular blocks and fantastic shapes of such complexity as to make description impossible. It most resembles an ice-dam formed during the spring on many of the northern rivers, except that the material is black and covered by numerous small craters caused by the escape of steam from beneath. In this irregular mass are numerous small caves formed by the piling up of blocks of basalt as well as by the recession of liquid lava leaving cavities with thin dome-like roofs. In these cavities the ice has collected during the spring and winter months and owing to the nonconducting character of the rock, does not completely thaw during the warm summer. It had been preserved by nature very much as ice is stored in northern climates, by packing in some nonconducting substance. In these

caves the ice appears as coverings on the floors and as stalactites (icicles) hanging from the ceilings.

Hematite, Fe_2O_3

This well known mineral, the anhydrous oxide of iron, is found everywhere and in a great variety of forms. It is abundant in all mines where oxidation of sulphides has taken place and is the cause of the red color of many ores, minerals and soils. When well crystallized it is called specular iron and frequently forms beautiful cabinet specimens especially when showing an iridescent tarnish. It is frequently found in Arizona as a contact mineral associated with epidote and similar minerals. It is further found in large beds where it can be utilized as a basic flux in smelting.

Magnetite, Fe_3O_4

This is the black magnetic oxide of iron, and is found as a microscopic accessory in nearly all rocks. From this source it finds its way into black sands and similar deposits. It is further found, like hematite, associated with contact minerals and in a great variety of ways. In the Tucson mountains it is found as rounded transported blocks, frequently pitted in a manner to resemble meteorites.

Pyrolusite, MnO_2

The Black oxide of manganese, or pyrolusite, has been noted in the Clifton-Morenci district mixed with limonite.[1] Samples from other localities have been received at the

[1] Lindgren: U. S. G. S., PP. No. 43.

University of Arizona, but data regarding their mode of occurrence are lacking.

Limonite, $Fe_2O_3 3H_2O$

Limonite, or the hydrous oxide of iron is very abundant; it is associated with oxidized ores in the Copper Queen mine where, together with hematite, it is the cause of the reddish color of the ores. It is frequently found in mammillary and kidney shapes. In general its mode of occurrence is similar to that of hematite, from which it can hardly be distinguished except by chemical means.

VI. OXYGEN SALTS

(1). CARBONATES

Calcite, $CaCO_3$

The various modifications of calcite are found in nearly every mountain range of the State and have frequently been described in geological literature.

Limestone.—This well known rock or mineral varies greatly in composition and appearance in different parts of the State. In many places especially in the vicinity of the Grand Cañon, it is very impure containing often large quantities of both silica and magnesia. The silica is sometimes in the form of nodules and geodes and sometimes as fine sand or silt intimately mixed with the carbonate. The magnesium is always in the form of magnesium carbonate. The following analyses made by the writer on samples obtained in the vicinity of Flagstaff will give an idea of its composition. In geological literature the formation is known as the Aubrey Limestone.

	No 1 Per cent.	No 2 Per cent.	No 3 Per cent.
Silica	34.10	17.00	72.21
Iron and alumina	1.60	1.00	2.91
Calcium carbonate	33.81	48.20	18.60
Magnesium carbonate	26.43	34.40	5.62
Total	95.94	100.60	99.34

It will be seen from the analyses that No. 3 at least is a calcareous sandstone rather than limestone, and in fact,

all gradation may be found in this district between pure sandstone on the one side and pure limestone on the other. The formation known as the Red Walled Limestone in the Grand Cañon is much purer in composition. A large area of this has been exposed in the vicinity of Flagstaff through the intrusive action of some of the crystalline lavas of the San Francisco mountain district. It is found in direct contact with andesite on the north flank of Elden Peak, about nine miles from town. It has been used in the manufacture of lime, and is said to give excellent results. Its chemical composition is represented in the table below.

Silica	0.27
Iron and alumina	1.24
Calcium carbonate	95.84
Magnesium carbonate	0.90
Alkalies	0.48
Total	98.73

An interesting case of contact metamorphism was observed at the immediate contact of this pure limestone or marble with the crystalline andesite. Here the limestone has become very fine grained and taken on the appearance of lithographic stone. The alteration is plainly due to the influence of the igneous mass by which the marble or limestone has become both silicified and dolomitized. The chemical reactions which have taken place in this transformation may be inferred from the following table, which contains the analysis of a sample taken about five feet from the contact.

	Per cent.
Silica	19.41
Iron oxide	2.02
Alumina	8.82
Calcium carbonate	46.30
Magnesium carbonate	25.43
Total	101.98

Marble.—Marble or crystallized limestone has frequently been used in Arizona for building purposes. The local demand, however, is very slight, and freight rates are such that it cannot be transported great distances. Samples sent to the University of Arizona, from various localities, seem to show that it is abundant and frequently of very pleasing color.

Onyx Marble.—This beautiful stone, more frequently known as Mexican Onyx, has been found in Arizona in tints and variegated effects equal in every respect to the Mexican product. Mineralogically it may be considered as stratified and variegated calcite or aragonite, the bands and irregular coloring effects being caused by the arrangement of such foreign pigments as iron oxide in various stages of oxidation and hydration. The most important locality in Arizona is near Mayers about 26 miles from Prescott. The deposit is approximately twenty acres in extent and the workable material is described as occurring in bowlders containing from two to thirty cubic feet.[1] Other localities are Greaterville, Kirkland Valley, and Oak Creek.

Caliche.—This is a word of Spanish origin loosely em-

[1] W. P. Blake: Rep. to Gov., 1899.

ployed by the Mexicans and others in the south-western United States and Mexico to designate almost any non-crystalline crust. It was perhaps first used by the Chillians who applied it to the soluble saline crusts of their country which consisted mostly of crude nitre and other soluble constituents. In some parts of California the term is still used in a similar manner, perhaps with particular reference to the top coatings.[1] In Arizona the term is usually applied to a calcareous deposit of varying hardness found to exist in many soils and gravels. It results from the evaporation of meteoric water in situ, and of water brought down from the mountains and distributed throughout the valley in the form of underground streams and reservoirs. The calcareous matter owes its ultimate origin to the decomposition, through the influence of dilute solutions of carbonic acid, of complex calcium silicates of the soil and rocks. The following reaction is given as an illustration of this decomposition:

$$\underset{CaAl_2Si_2O_8}{\text{Lime Feldspar}} + \underset{KAlSi_3O_8}{\text{Alkali Feldspar}} + \underset{H_2CO_3}{\text{Carbonic Acid}} =$$

$$\underset{CaCO_3}{\text{Calcite (caliche)}} + \underset{H_2KAl_3Si_3O_{12}}{\text{Muscovite (sericite)}} + \underset{2SiO_2}{\text{Quartz.}}$$

The reaction furthur explains the presence of alkali in the soil, since the continued action of CO_2, or H_2CO_3, would convert the muscovite into K_2CO_3 and kaolin. The two constituents kaolin and alkali may also be formed direct from the feldspar as shown by the following reaction:

[1] Bailey: The Saline Deposits of Cal., Bul. No. 24, Cal. State Min. Bureau.

$$\underset{6KAlSi_3O_8}{\text{Orthoclase}} + \underset{6H_2O}{\text{Water}} + \underset{3CO_2}{\text{Carbon Dioxide}} =$$

$$\underset{3H_4Al_2Si_2O_9}{\text{Kaolin}} + \underset{3K_2CO_3}{\text{Alkali}} + \underset{12SiO_2.}{\text{Silica.}}$$

The alkali is not found to any extent in the caliche, since its great solubility compels it to remain mostly in the underground waters. The kaolin, or clay, and the silica represented in the above reaction are always present in large quantities. The muscovite then is only an intermediate product, easily seen in decomposing rocks by means of the microscope, but later altering into kaolin or clay. As may easily be inferred, caliche is a deposit occurring only in arid countries where evaporation is rapid and circulation of at least surface waters slow and incomplete. It is therefore abundant in Arizona and in arid portions of California and Mexico. In appearance it is a light buff shading to white, and seems to be made up of the ordinary constituents of the soil such as silt, sand, gravel and small pebbles firmly cemented together by calcium carbonate. Occasionally it is faintly stratified, the layers being due to successive depositions from solution rather than sedimentation. As a deposit in ordinary soils it is always formed beneath the surface; where erosion has not taken place, there are a few inches to several feet of earth on top. Its occurrence, however, is not limited to within a few feet of the surface; it is sometimes found in layers of varying thickness alternating with loose sand or gravel to a depth of seventy-five feet or more. The deeper layers differ somewhat in character from those near the surface. These usually consist of coarser particles of gravel

and pebbles and of even small bowlders cemented by a more crystalline calcium carbonate into a mass of such hardness that a well can be sunk into it only with the greatest difficulty. Indeed, it is sometimes necessary to resort to the use of blasting powder. The spaces between the pebbles are lined with drusy scalenohedral crystals of calcite and even well formed geodic cavities are sometimes observed. Evidently the deposition here took place under more uniform and deeper seated conditions than those which gave rise to the finer grained amorphous surface deposits. The deposit is not merely local in character, but many hundreds of square miles are rendered useless for agricultural purposes by its presence.

As previously stated, it would seem that the two modifications of this deposit described above owe their origin to two closely related phenomena: (1), the layers near the surface, to the evaporation of meteoric waters in situ; (2), the deep-seated layers, to evaporation of waters brought up by capillary attraction to some definite position which depends upon local conditions, such as fineness of material, pressure, etc. Of course it can easily be seen that where underground waters exist near the surface the top layers might be formed in the way last mentioned. Then evaporation at depth would not take place. Again, in places where there is no underground water at reasonable depths, only the first mentioned cause would be operative. In either case the deposition takes place beneath the surface and never precisely upon it. The reason for this is to be found in the climatic conditions of the Southwest. Immediately after a rain the sun quickly reap-

pears, rapidly drying the surface of the ground and thus preventing furthur action of capillary attraction. The earth becoming like a dry sponge is unable to soak up moisture from below. The depth to which this superficial drying takes place depends upon local conditions such as texture of the soil, vegetation and other features. The remaining meteoric water is now brought up by capillary attraction to the point where evaporation begins and capillary attraction ends. This action continues until all of the water is evaporated, is repeated after the next rain, thus giving rise to faint stratifications, until finally a deposit of considerable thickness is formed.

The deposition taking place through the evaporation of underground waters may progress at any depth, though with less rapidity as the depth increases. The exact position in which the deposit is forming during any series of years depends, first, upon the height of the underground water, and second, upon the distance through which capillary attraction is able to act under the existing conditions of porosity, pressure, or other determining agents. Thus, if the underground water at a certain time is found at a depth of say eighty-five feet, the calcareous deposit may actually form at that time at a depth of seventy-five feet or more. Cavities are actually found at this depth incompletely filled with minute crystals, a fact which suggests that the deposition is still going on.

The explanation of the alternate layers of calcareous material is to be sought in the possibility of the underground waters having occupied higher levels in former

periods of time. The Tucson Valley, for example, is filled with débris contributed by the high surrounding mountains. All of this material was at one time on the slopes and mountain tops of these ranges. Their altitude, then, must have been a few thousand feet higher than the present time. As is well known this would have had the effect of greatly increasing the annual precipitation which in due course would have greatly augmented the quantity of underground water. Regarding the outlet of the underground water there is at present but little known, but it is very probable that erosion and the solvent action of water has had the effect of decreasing its elevation. Thus it seems quite evident from well established facts of geology that the underground water of this valley, occupied in former periods of time considerable higher levels. Evaporations at points slightly above these surfaces, as described above, would account for the repetition of the caliche beds.

Caliche, as the term is used in Arizona, was first fully described in scientific literature by Professor W. P. Blake,[1] who explained its origin as entirely through evaporation of underground waters brought up from below by capillary attraction. Dissenting from this view, Professor R. H. Forbes holds that all of these deposits, even the deep-seated ones are formed by the evaporation of rain water which has percolated to a depth of three or four feet, decomposing the constituents of the soil through the action of carbon dioxide. The calcareous

[1] The Caliche of Southern Arizona: Trans. Am. In. Min. Eng., 31, 1901, p. 220.

material thus formed is left behind in the soil on evaporation of the water, a process which is repeated until a limy hardpan is formed. "The different layers formed at different depths below the surface mark the various levels which for geological reasons remained constant for a long enough period of time to permit the formation of a layer of caliche just below the surface of that time."[1]

Professor C. F. Tolman would confine the term caliche to the amorphous surface crusts and not the crystalline cements of the desert gravels. "This cement," he states, "is primarily due to the fact that these basins are practically undrained. The deeper cement, moreover, may be largely recrystallized crusts, and without direct relation to any change in climate or water level."[2] Professor Tolman also calls attention to the probability of the Paleozoic limestones being an original source of much of the calcareous material.[3]

Siderite, $FeCO_3$

This mineral, sometimes known as spathic iron, is frequently developed in Arizona as an alteration product near limestone especially where sulphides of iron are oxidizing. In the Tucson mountains it has been observed as a decomposition product of the ferromagnesian constituents of basic lavas, in which it is deposited in amygdaloidal cavities and cracks together with chalcedony, calcite and agate.

[1] Quoted in Underground Waters of Salt River Valley, U. S. G. S., W. S. P., No. 136, p. 110.

[2] Manuscript.

[3] Pub. 113, Carnegie Inst. of Wash., 73.

Rhodochrosite, $MnCO_3$

So far as the writer knows, this mineral in a pure condition has not been reported from Arizona. A manganiferous limestone, however, is found in the Tombstone district and on decomposition yields manganese oxide containing silver.[1]

Cerussite, $PbCO_3$

The carbonate of lead, a heavy and when pure a white or transparent mineral, is frequently met with in the lead and silver mines of the State as an alteration product of galena. The galena first oxidizes to the sulphate or anglesite, and then coming in contact with solutions containing carbonates a substitution takes place by which the sulphate radical is removed and the carbonate radical installed. A crystallographic study has been made by Pirsson on samples from the Red Cloud mine.[2] In the Bisbee district it is found in Hendricks Gulch associated with limestone. Here it occurs as an impure friable mass which in mining breaks up into fine sand. Hence this variety is sometimes known as cerussite sand.

Azurite, $2CuCO_3.Cu(OH)_2$, and Malachite, $CuCO_3.Cu(OH)_2$

The blue and green carbonate are abundant in Arizona and have been so frequently mentioned in the description of mining districts that little space will be devoted to them here. The two minerals are nearly always associated with each other even in the same hand specimen, sometimes so intricately mingled in delicate wavy forms as to yield very striking and beautiful effects when polished.

[1] W. P. Blake: Rep. to Gov., 1899.
[2] Am. Jour. Sc., 42, p. 405.

The crystalline varieties of azurite sometimes develops in aggregates of rounded bunches, arranged in such a manner as closely to resemble clusters of grapes. The green carbonate more often appears as silky radiating tufts or incrustations on botryoidal surfaces, giving the appearance of green plush. These beautiful forms are found as the lining of caves or small cavities. Here also are frequently developed stalactites containing both minerals in concentric layers. Cross sections of these when polished show concentric wavy rings of blue and green carbonates. Dr. G. F. Kunz has applied the name azurmalachite to such samples when employed as a gem.

These two minerals are always secondary and are never found at great depths. They result from the oxidation of the various sulphides of copper by which action the soluble sulphates are formed, which on coming in contact with limestone or carbonated waters, react to form the carbonates. These are then deposited from solution in the delicate forms described above.

Aurichalcite, $2(Zn, Cu)CO_3.3(Zn, Cu)(OH)_2$

This rare mineral occurs in pale green and bluish flakes. It has been reported from the Copper Queen mine at Bisbee and from the Catalina mountains. (Dana).

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(2). SILICATES

The Feldspars

Orthoclase, $KAlSi_3O_8$.—This is a rock-forming mineral, and as a constituent of granite and the corresponding

acid eruptives, such as rhyolites, felsites, and quartz porphyries, is found almost everywhere in the State. In this mode of occurrence it develops in crystals varying from microscopic size to crystals an inch in length. In pegmatites, or the light colored veins which are nearly always found crossing granites and similar rocks, it is found associated with quartz and sometimes developed in large masses of pure material. In the pegmatites of southern California masses of this kind are frequently found weighing more than 75 pounds and possessing uniform cleavage and structure. Good crystals are frequently found ten inches in length. In Arizona there are no unusual deposits of this mineral. A few good crystals have been found in the pegmatites of the Catalina mountains, near Tucson, and good white masses may be observed in many other localities. The Rincon mountains have yielded rather fine samples of typical pegmatite.

Microcline.—This mineral, which has the same chemical composition as orthoclase, with slightly different crystalline structure, has been observed as a microscopic constituent in the tourmaline aplites found in the vicinity of Oracle, in the Catalina mountains.

Plagioclases.—The plagioclase feldspars differ from orthoclase in composition and crystallization. Chemically they are isomorphous mixtures of albite, $NaAlSi_3O_8$, and anorthite, $CaAl_2Si_2O_8$, different proportions of these two molecules giving rise to the rather arbitrary varieties, oligoclase, andesine, loboradorite and bytownite. They are all rock-forming minerals and are found in diorites,

gabbros, and their eruptive equivalents, andesites and basalts. Andesites are probably the most common eruptive in the Territory, and as constituents of these the plagioclases or triclinic feldspars are very abundant.

Pyroxene

Pyroxene, the common variety of which is augite, is a complex silicate of calcium, magnesium, iron, etc. It is a rock-forming mineral, and is abundant in Arizona as a constituent of andesites, basalts and other rocks.

Amphibole

This mineral is similar to pyroxene in its chemical composition and variations. Like pyroxene, it is very abundant everywhere as a rock-forming constituent of granites, andesites, dike rocks and metamorphic schists. It is a constituent of the more acid and intermediate rocks, while pyroxene usually indicates a more basic magma. Actinolite and tremolite are the light colored varieties, and are frequently found as constituents of the crystalline schists. A manganiferous variety, exact locality unknown, has been analyzed by Mr. Fred. Hawley, a student at the University of Arizona, with the following results :

	Per cent.
Silica	49.30
Ferrous oxide	15.14
Alumina	3.10
Manganese oxide	6.39
Calcium oxide	23.61
Magnesia	0.14
Undetermined	2.32
Total	100.00

The mineral is dark brown with columnar divergent structure. The above analysis would place the mineral as near dannemorite.

Garnet

Garnet is a complex silicate of calcium and aluminium in which calcium is frequently replaced by more or less iron and magnesium, and the aluminium by chromium and iron. It varies in color from white to black, red, yellow, green and brown shades being the most common.

Garnetiferous Sand.—Garnet is a frequent accessory in schistose and granitic rocks. These are yielded up by the rock on disintegration and owing to their ability to resist erosion and corrosion collect in the eddies of the stream together with black sand or magnetite. Samples illustrating this mode of occurrence have been collected from the streams of the Catalina mountains which on analysis are found to correspond to the manganiferous variety or spessartite.

Precious Garnet.—In the exteme northern part of the State the Moki Indians and others bring into the towns large quantities of loose garnets many of which are cut and show a beautiful dark ruby tint. They are known among gem dealers as the Arizona rubies and are without doubt the finest garnets in the United States. They are picked up in gravel deposits and around ant-hills where these industrious workers have brought them from the surrounding country. The associated minerals are peridot, pyroxene, magnetite and similar minerals. The gem has never been found in place but

owing to its associations, one is authorized in assuming that it was developed in some of the ultra-basic rocks such as the peridotites. They are always found in well rounded and polished pebbles varying from a few millimeters to two centimeters in diameter. The latter, however, are never of gem quality. The average size for cutting is about one carat; two carat stones are abundant but the three carat size is very scarce. The smooth polished surfaces of these fragments seems to be due to wind erosion rather than stream. (See Mineral Resources, 1908.) The index of refraction of these gems as determined with sodium light on a Fuess instrument is 1.7500. This corresponds to the variety pyrope.

Yellow garnet, or variety containing larger quantities of lime, has frequently been received at the University of Arizona for identification, and a fine large crystal from Gila Cañon has been described by Mr. Kunz.[1] The mineralogical name for this variety is Grossularite.

Massive Garnet.—This variety of garnet is very common in many of the mining districts of the State having been developed by contact action between limestone and igneous intrusion. This modification varies in color from nearly black to light yellow according to the acidity of the magma. Near the contact with basic eruptives the dark colored varieties are formed. It is found in the Clifton-Morenci district in altered limestone in the form of andradite, or common iron garnet, yellow to dark brown in color and of a resinous luster. It is further found in the same locality intergrown with magnetite,

[1] Gems, p. 79.

pyrite, zinc blende and chalcopyrite.[1] It is is also abundantly developed in the Silver Bell, the San Xavier, Washington Camp and other contact districts.

Chrysolite, $(Mg, Fe)_2SiO_4$

This is usually a yellowish green mineral consisting of an isomorphous mixture of the two constituents, iron and magnesium silicate. It is usually a rock-forming mineral, and as such is more frequently known as olivine. It is a normal constituent of basalts and most gabbros, and in these varieties of rock is of very common occurrence in Arizona. The crystals are usually so small as to escape ordinary observation. Yet in some of the basalts of the San Francisco mountains crystals are found more than one-half inch in length.

Peridot.—Crystals of sufficient purity and transparency to be useful as a gem are known as peridot. It is found in beautiful tints near Talkai, and is frequently collected, together with the red garnets with which they are sometimes found, by the Indians and prospectors. A crystal from this locality, exhibited at the World's Fair, at Portland, in 1905, after being cut, was a beautiful gem of 25¾ carats. It was pale yellowish green and took a brilliant polish. The gem variety of chrysolite is most often found in the streams as worn pebbles, but is occasionally found lining cavities in basaltic lavas of sufficient clearness to be used as a gem. Like garnets, they are found around ant-hills. One hill investigated by members of the United States Geological Survey was found to be made up of 75 per cent. of peridot grains, the remainder

[1] U. S. G. S., PP. No. 43.

being garnet, quartz, diopside, etc. They are brought to the hills from the surface over an area of many square feet surrounding the ant houses.

Wollastonite, $CaSiO_3$

This is a contact mineral sometimes developed where igneous rocks of intrusion come in contact with limestone. When pure it is a white mineral of pearly luster and breaking into splintery forms. Contact deposits are of common occurrence in Arizona, but this mineral has not been described from many localities. It has been mentioned among the contact minerals in the Clifton-Morenci district.[1]

Willemite, Zn_2SiO_4

This anhydrous silicate of zinc is usually a light yellow mineral somewhat resembling yellow garnet. It has been observed in Arizona only in very small quantities in the Clifton-Morenci district, on the north side of Modoc mountain. It was first discovered here by Mr. Boutwell, and identified by Messrs. Pirsson and Penfield, of Yale. It is described as occurring in stout hexagonal crystals with the usual characteristics of the mineral.[2]

Dioptase, H_2CuSiO_4

This rare, gem-like silicate of copper is found in the Clifton-Morenci district, as noted by Hill.[3] The crystals occur in beautiful emerald green incrustations lining cavities and associated with ferruginous matter and

[1] U. S. G. S., PP. No. 43, p. 124.
[2] U. S. G. S., PP. No. 43.
[3] Am. Jour. Sci., 3d series, 23, p. 325.

chrysocolla. It has been further reported from near Riverside, by W. B. Smith.[1]

Vesuvianite

This is a complex silicate containing calcium, aluminium and a small amount of fluorine. It is frequently developed in contact metamorphism together with garnet and epidote. In appearance it resembles the latter mineral closely, but may be distinguished from it easily by the absence of iron; epidote becomes magnetic on heating before the blowpipe, while vesuvianite does not. Samples have been received at the University from the vicinity of Jerome, but data regarding the mode of occurrence are lacking. It doubtless occurs in other localities in the State, but has not been described or else has been mistaken for other minerals which it resembles.

Zircon, $ZrSiO_4$

This mineral has been noted in Arizona in the Clifton-Morenci district only as a microscopic accessory in granite and porphyry.[2]

Topaz, $(AlF)_2SiO_4$

Samples of this mineral have been received at the University from localities in the northern part of the State in the form of white broken fragments, much resembling quartz, for which it has frequently been mistaken. It can be easily distinguished from that min-

[1] Proc. Colo. Sci. Soc., 2, p. 159.

[2] Lindgren: U. S. G. S., PP. No. 43, p. 102.

eral, however, by its superior hardness and its cleavage. The exact locality of these samples is not known.

Andalusite, Al_2SiO_5

The silicate of aluminium known as andalusite is developed in slates and other sedimentary deposits through the influence of both regional and contact metamorphism. In rare instances it has been observed as a pyrogenic constituent of igneous rocks. Thus in Arizona it has been observed as a microscopic accessory in the granites in the Globe copper district. It has been suggested that possibly the mineral has been developed here through recrystallization brought about by metamorphic action, and is not an original constituent as it would seem.[1]

Cyanite, Al_2SiO_5

This is a pale blue bladed mineral of the same composition as andalusite, and though appearing quite different from it, occurring in a similar manner. In a ground mass consisting of quartz and mica, it is found north of Yuma in the form of small stout crystals about one-half inch in length. In the same locality it is further found associated with dumortierite.

Epidote, $HCa_2(Al,Fe)_3Si_3O_{13}$

This mineral is a silicate of calcium, iron and aluminium, and can usually be easily recognized by its peculiar yellowish green color. It is abundantly developed in Arizona as the result of contact metamorphism; hence it is found associated with garnet and other products of this

[1] Ransome: U. S. G. S., PP. No. 12, p. 66.

action in most of the mining districts. It is further formed as the result of other secondary decomposition in nearly all kinds of rocks, both sedimentary and volcanic. It may appear as greenish incrustations on the surface of rocks or as filling in minute cracks. In the Tucson mountains it has been observed as a decomposition product in light colored rhyolites where it appears as green blotches through the specimen. Some of the spots are rather angular and are thought to be pseudomorphs after feldspar. In the same locality it is found in dark andesitic rocks, as thin incrustations along the joint planes. This mineral being of such wide occurrence is usually found in the streams and washes as greenish pebbles, and as green stains on other fragments. The association of epidote and native copper has been described under Copper.

Gadolinite

This is a silicate of glucinum, iron, the rare yttrium earths, and cerium. It is quite abundant in the mineralized pegmatites of Norway and Sweden, but extremely rare elsewhere. In Texas it has been found in nodular masses and rough crystals of large size. In 1908 a deposit was found near Kingman, Arizona, and several tons of the material have already been shipped East for the extraction of rare earths employed in the preparation of the well-known mantles for incandescent gas light. The mineral from this locality presents the usual appearance of dark brown to black glassy masses of conchoidal cleavage not unlike ordinary obsidian. It has, however, a very much higher density. It occurs associated with

the new mineral, arizonite, in what seem to be pegmatites. Mr. Chase Palmer has made a partial analysis, the results of which are given below.[1]

	Per cent.
SiO_2	24.41
Yttrium earths	36.86
Cerium earths	11.50
BeO	11.50
FeO	11.56

Calamine, H_2ZnSiO_5

The hydrous silicate of zinc, or calamine, has been reported as occurring in minute quantities on garnet rock in the Shannon mine in the Clifton-Morenci districts.[2]

Tourmaline

This is a complex silicate of boron, aluminium and similar elements. As stout black hexagonal crystals, sometimes bent and faulted it is found in the Catalina mountains near Oracle. It is here occasionally disseminated through the mass in such a manner as to constitute a typical tourmaline granite. It is not found in large masses, however, and is simply a local condition along the borders of the main granitic material. A microscopic examination shows it to be associated with quartz, plagioclase, orthoclase and microcline. Tourmaline seems to be very widely distributed throughout the State as shown by the frequent samples received for identification at the University of Arizona. Among these have been observed frequently fibrous and even granular modifications of the mineral.

[1] Am. Jour. Sci., 28, 353.

[2] Lindgren: U. S. G. S., PP. No. 43, p. 111.

Dumortierite

This is a rare silicate of aluminium with a small per cent. of boron. It is of a beautiful blue color and has frequently been mistaken for copper minerals. It is frequently found in the form of float or loose rounded pebbles in the vicinity of Clip, north of Yuma. It is associated with rather granular quartzite-like rock highly metamorphic and sometimes so intimately mixed that the entire specimen appears blue. Under the microscope however, thin sections show that the mass is made up of fine needles and bunches of radiating crystals embedded in the quartzite. The mineral shows beautiful pleocroism, the color parallel to the elongation being a deep blue, while the other two directions give nearly colorless and pale violet. The quartz is well crystallized, appears in rounded individuals with sharp contacts and contains numerous gas and liquid inclusions. The gas bubble is frequently found to be in motion. The mineral from Clip has been analyzed by Diller[1] and Ford[2] both of whom found noticeable quantities of boron oxide. These analyses are of value since they show that the mineral is to be considered as a compound containing boron and not a simple silicate as formerly. The Arizona locality is of especial interest since here the mineral seems to be found in a metamorphic rock rather than in pegmatites the more usual mode. The presence of the gas inclusions prove, however, that the metamorphism is of a deep-seated type.

[1] Am. Jour. Sci., 3d series, 37, p. 216.
[2] Am. Jour. Sci., 4th series, 14, p. 426.

Mica

There are several varieties of mica varying in composition and appearance, but all possessing the well-known cleavage and yielding elastic plates.

Muscovite.—This variety is the common white mica and is a frequent constituent of rocks and soils. In large crystals it frequently developes in pegmatites or the white vein-like formations seen crossing granite and similar rock masses. It is further a constituent of metamorphic schists. Sericite, a closely allied variety has been fully described by Ransome in the schists of the Bisbee Quadrangle,[1] and by the same author in similar rocks of the Globe district.

Biotite, or the black mica, is similar in composition with the exception that it contains iron and magnesium. It is abundant in Arizona as a rock-forming mineral in the biotite granites, gneisses and metamorphic schists.

Doubtless other varieties of mica are to be found in Arizona, but as yet they have not been investigated.

Serpentine

This is a hydrous magnesium silicate, a secondary mineral resulting from the alteration of such minerals as olivine, pyroxene, hornblende, etc. Such rocks as the peridotites, which are made up almost entirely of these minerals, yield on disintegration large deposits of serpentine. It is a rather soft mineral, usually of greenish color and a slight soapy feel.

[1] U. S. G. S., PP. No. 21, p. 25.

Ordinary Serpentine. — Impure massive serpentine is found associated with magnetite in the Dos Cabesas mountains. A similar mode of occurrence has been noted by Lindgren in the Clifton-Morenci district in the Thompson mine.[1]

Chrysotile or Asbestos.—This is the crystallized or fibrous variety of serpentine and is known on the market as asbestos. It is found in the granite gorge of the Grand Cañon, 4,000 feet below the rim on the north side of the river, where it is mined by the Hance Asbestos Co. The fibers are of excellent quality, of good length and very flexible. The mineral occurs in cracks or seams in the rock where the fibers have arranged themselves perpendicular to the surfaces. The asbestos seems to be associated with limestone which has become altered through the contact action of intrusive diabase. It is supposed to have resulted from the hydration of the pyroxenes. While the material is, perhaps, of the finest quality of any found in the United States, its inaccessibility makes it difficult to work the deposit with profit.[2] Another locality has been reported from a place twenty miles west of Globe where it occurs in seams in massive serpentine.

Talc

This well-known mineral is also a decomposition product of ferromagnesium minerals and is frequently met with in the vicinity of mines where metamorphic agencies are at work. It is lighter in color and softer than ser-

[1] U. S. G. S., PP. No. 43.
[2] Mineral Resources, 1908.

pentine. No unusual or particular interesting mode of occurrence has been observed in Arizona.

Kaolinite, $H_4Al_2Si_2O_9$

Kaolinite, or as it is more commonly known, kaolin is a secondary mineral resulting from the decomposition of feldspathic minerals. It is consequently always found where weathering and erosion are going on and is hence a constituent of all soils. Only, however, where conditions are favorable for a sorting action in quiet water by which the fine clayey material is separated from the sand and gravel, is it found in a comparatively pure state and in quite large deposits. In Arizona, the débris from the mountains is brought down by flood waters and periodically spread upon the plain, a condition very unfavorable to the formation of deposits of kaolin or clay. Yet these deposits, further worked over by less flooded conditions, sometimes give rise to deposits still containing large amounts of sand, but of sufficient purity to be used locally for the manufacture of red brick, making it possible for the large towns of the State to have their brickyards where a product of fair quality is manufactured.

Pure Kaolin.—This is frequently met with in the form of soft putty-like masses in many of the mines where it has resulted from a kaolinization of the feldspars. In the Clifton-Morenci district it is reported as accompanying chalcocite in the porphyry; in small veinlets in quartz at the Hombolt, Ryerson and other mines; in mammillary masses associated with azurite malachite in the Longfellow mine.[1] Associated with limonite, it is found in

[1] U. S. G. S., PP. No. 43.

large quantities in the Copper Queen mines, where it has been selected and used as a binding material for the quartz used in lining the converters.

Graphitic Clay.—A large deposit of this variety of clay is found about seven miles from Benson. It is black and closely resembles soft coal. When ground to a fine powder and mixed with water it becomes very plastic. The black color disappears on burning, the mass assuming a buff color. The material has been used for the manufacture of pressed brick and is still extensively used in converter plants as a binding material, in Cananea, Bisbee and other mining localities. The deposit is said to be almost unlimited in extent. Its composition is illustrated by the following analysis:

	Per cent.
Silica	59.15
Iron and alumina	27.52
Calcium carbonate	2.82
Water and undetermined	10.51

Cement Clay.—Doubtless clays or shales of good quality for the manufacture of Portland cement could be found in many places in Arizona were the field throughly prospected. At present, however, high freight rates and small local markets combine to make the outlook for the cement industry in Arizona rather discouraging. A government plant has been in operation at Roosevelt where the product was used for the construction of the Tonto dam. The clay found here has the following composition:

	Per cent.
Silica	51.91
Iron and alumina	23.70
Lime	6.10
Magnesia	0.97
Water	13.40

Limestone of good quality to combine with the clay is found in the immediate vicinity.[1]

The writer has investigated clay deposits in the vicinity of Flagstaff and found material of very satisfactory composition for the cement industry. Here it results from the decomposition of black basaltic and andesitic rocks and has collected in a depression caused by a series of lava flows in what is known as Rogers Lake. The deposit is about 700 acres in extent and varies in thickness from three feet near the edges to nine feet near the center. It is yellowish grey, very tough and plastic. Its composition is as follows:

	Per cent.
Silica	52.94
Alumina	17.91
Iron oxide	9.23
Lime	1.22
Magnesia	0.42
Alkalies	2.22
Water, etc	16.34
Total	100.28

A burning test was made on this material using 100 parts of clay to 300 parts of limestone. An excellent quality of cement resulted.

[1] U. S. G. S., Bul. No. 243, p. 87.

Chrysocolla, $CuSiO_3, 2H_2O$

This is a light blue compact mineral, much resembling turquoise, quite common near the surface in many of the mines in the State. In the Globe district it is known to be very abundant, where it occurs in veinlets in impure cuprite, in mineralized porphyry, and in associated oxidized minerals. Very beautiful samples are sometimes found in which the delicate blue mammillary masses are covered with thin crusts of drusy quartz crystals. The mineral as found in the mines is much harder than expected from the descriptions in the textbooks. This is because of the silicious matter present as impurities; in fact, a great deal of the material thought to be chrysocolla is in reality quartz or silica stained with copper minerals.

Lettsomite

This is a rare silicate of copper and aluminium. The mineral is sky-blue, fibrous and possesses a silky luster. It has been found in a silicious rock in Arizona in the form of small seams.[1]

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(3) PHOSPHATES, VANADATES, ETC.

Apatite, $CaFl, Ca_4(PO_4)_3$

This is found as a universal microscopic accessory in both granitic and eruptive rocks. It appears as minute colorless needles, sometimes tufts, but more often as isolated crystals in the more basic constituents of the

[1] Genth: Am. Jour. Sci. 3d series, 4, p. 119.

rock. As shown by chemical analysis, it is probably a constituent of all soils, its ultimate origin being the microscopic crystals mentioned above.

Ecdemite

This rare chloro-arseniate of lead has been observed as soft drusy incrustations on wulfenite crystals from the Mammoth mine in the Catalina mountains. It is of an orange color, about the same tint as the wulfenite, and can hardly be distinguished from it. Under the microscope, however, the crystallization can easily be distinguished.

Mimetite

This also is a rare chloro-arseniate of lead appearing usually as pale yellow incrustations consisting of rounded aggregates. It has been reported from a locality a few miles northwest of the Vulture mine.[1]

Vanadinite, $PbCl, Pb_4(Vo_4)_3$

This rare and beautiful mineral is frequently met with in Arizona, particularly in quartz veins carrying gold and silver. In composition it is a chloro-vanadate of lead, and ordinarily can be easily recognized by its hexagonal crystallization and its striking red color. It generally appears as incrustations and isolated implanted crystals, sometimes barrel shaped, but more often of good hexagonal development. It is found in the cavities of the vein filling material, a fact which proves that it was deposited during the last stages of mineralization. It is sometimes found even encrusting calcite. Important localities in Arizona are the Red Cloud mine, Yuma Co.,

[1] Am. Jour. Sci., 3d series, 22, p. 202.

the Mammoth mine at Schulz, in the Catalina mountains, Pima Co., and the Old Yuma mine, about 14 miles northwest of Tucson. Minerals which are most often associated with it are, wulfenite, cerussite, ecdemite and descloisite. In the Globe district, where it is also quite common, it occurs along prominent fault fissures in the Apache quartzites.[1] In all of these cases the mineral is found filling cavities and seams in the country rock in the immediate vicinity of the vein as well as in the vein itself. This is especially true of the deposit in the Yuma mine where good vein filling has progressed to only a limited extent. Here the vanadinite and associated minerals may be found implanted on the surface of planes formed by fractures in the country rock. Fine museum specimens are sometimes found which consist of a slab of the country rock first covered with a layer of calcite, then vanadinite and finally a thin layer of descloisite. Crystals have been found over one-fourth inch in diameter.

The origin of this mineral or the chemical changes which have been concerned in its production are points which have not yet been worked out. Dr. Hillebrand has called attention to the wide distribution of vanadium in the rocks of the United States,[2] and the universal occurrence of apatite with which this mineral is isomorphous, as microscopic accessories in rocks, is well-known. It may be possible then that the mineral originally existed in minute traces in the apatite molecule in which case the mineral might easily become concentrated by

[1] C. F. Tolman : Private Communication.

[2] U. S. G. S., Bul. No. 305, p. 19.

simple solution, without the intervention of complex chemical reactions. The mineral, however, has been produced artificially by Weinschenk[1] by bringing together, at moderately high temperatures, chloride of lead and vanadium compounds. This investigation would seem to show that if the vanadium originally existed in the complex basic silicate molecule, reactions with lead chloride could take place which would give rise to the mineral.

Libethenite, $Cu_3P_2O_8$, $Cu(OH)_2$.

This is a green basic phosphate of copper. In has recently been found in the Coronado mine in the Clifton-Morenci district, as small olive-green crystals less than one millimeter in length. It is associated with quartz and needles of malachite. The mineral was identified by Professor Penfield of Yale and the Caronado mine is probably the only known locality containing it it the United States.[2]

Descloisite and Cupro-descloisite

These minerals are basic vanadates of lead and zinc usually containing varying quantities of copper and manganese. In Arizona they are nearly always found associated with wulfenite and vanadinite. The most characteristic appearance is that of lustrous bronzy or black incrustations rarely more than one or two millimeters in thickness. In some cases the appearance is very much like that of thin varnish on the surface of other minerals.

[1] Brauns: Chemische Mineralogie, p. 270.

[2] U. S. G. S., PP. No. 43.

They are found deposited on calcite, wulfenite and vanadinite crystals, and hence are deposited later. Well-known localities in Arizona are the Castle Dome district, Tombstone, Mammoth mine in the Catalina mountains, and the Old Yuma mine in the Tucson range of mountains. The writer has analyzed this mineral from two widely different localities, the results of which are given below. No. 1 was from the Old Yuma mine in the Tucson mountains, and No. 2 from the Argentine Republic. No. 1 appeared as crystalline incrustations on crystals of vanadinite. These were chosen in preference to the incrustations found on calcite for the reason that it was believed that possible contamination from this source would not be so serious as from the calcite. No. 2 appeared as distinct orthorhombic crystals about two millimeters in length. Analysis No. 2 was conducted in the Fresenius Chemical Laboratories in Wiesbaden, and recognition is due Dr. H. Fresenius and Dr. W. Fresenius for permission to carry on the investigation as well as valuable suggestions regarding the method of analysis.

	No. 1		No. 2	
	Per cent.	Ratios	Per cent.	Ratios
Cl.....	——	——	0.08	——
Insoluble ..	——	——	0.78	——
As_2O_5.....	——	——	0.11	——
PbO.....	52.26	0.2345	53.36	0.2393
CuO.....	11.64	0.1462	1.21	0.0152
FeO	——	——	0.56	0.0077
ZnO.....	6.71	0.0824	13.15	0.1615
MnO	2.16	0.0304	4.56	0.0642
V_2O_5	23.02	0.1262	23.05	0.1263
H_2O	2.52	0.1400	2.27	0.1261
Total....	98.31		99.13	

Reduced to simpler terms, these ratios become:

	No. 1	No. 2
RO	0.4935 = 4	0.4879 = 4
V_2O_5	0.1262 = 1	0.1263 = 1
H_2O	0.1400 = 1	0.1261 = 1

The formula then becomes $(RO)_4 . V_2O_5 . H_2O$, or, $R_3(VO_4)_2 . R(HO)_2$, which is that usually given to this mineral.

The method of analysis briefly outlined is as follows: The finely divided mineral is dissolved in strong nitric acid, diluted and the insoluble residue filtered off, ignited and weighed. In the filtrate, chlorine is determined by means of a standard solution of silver nitrate. The silver chloride is filtered off after adding a few drops of chlorhydric acid to precipitate excess of silver used in titration. The lead is then precipitated with H_2SO_4, removed and weighed. The filtrate is now evaporated to dryness to remove nitric acid. Any further precipitate of lead sulphate is filtered off and weighed. The solution, properly diluted, is now precipitated with H_2S, the precipitate dissolved in nitric acid and reprecipitated. It is then dissolved again and the copper determined iodometrically. The two filtrates from the H_2S precipitation are combined, oxidized with nitric acid, and the iron, manganese and zinc separated from vanadium by precipitation with sodium carbonate twice repeated (three precipitations). The three filtrates containing vanadium are combined, evaporated with H_2SO_4 to remove nitric acid, diluted and reduced with H_2S. After removal of H_2S by boiling and passing in CO_2, the vanadium is determined by titration

with a standard solution of permanganate. The precipitate of iron, zinc and manganese is now dissolved in HCl and precipitated with NH_4OH, the precipitate redissolved and a basic carbonate precipitation of iron made with ammonium carbonate. The precipitate is again dissolved and precipitated with NH_4OH. The iron is then ignited and determined in the usual way. The three filtrates containing manganese and zinc are combined, the zinc precipitated with H_2S in a very slightly acid solution (with H_2SO_4), filtered off and ignited in a Rose crucible with hydrogen. The manganese is then precipitated with $(NH_4)_2S$ in an alkaline solution and the MnS ignited in the same manner as the zinc.

Erythrite, $Co_3As_2O_8.8H_2O$

This mineral is sometimes known as cobalt bloom on account of its delicate flower-like tint and frequent radiating structure. It is a very rare mineral but has recently been discovered near Jerome where it occurs as soft powder-like incrustations on a dark colored gangue containing disseminated grains of cobaltite. It is of a delicate pink color as usual but good crystallizations have not been observed. The deposit is being exploited for the cobalt and already some of the ore has been shipped to New Jersey for treatment. Accurate information regarding the mode of occurrence and associations has not yet been obtained.

Turquoise

Mineralogically this gem mineral is a phosphate of alumina and copper. Because of its delicate blue color

it has been highly prized by the prehistoric people of western United States and Mexico. It is, therefore, found in many of the Aztec ruins in Mexico and in ruins, of perhaps similar origin, in Arizona. It is found in situ in the Dragoon mountains, on the road between Pearce and Gleason, where it occurs in a greatly decomposed rock, perhaps a kaolinized rhyolite, in the form of irregular patches and veinlets. When these deposits were first discovered, there were abundant evidences of mining in a crude way, doubtless the work of some Indian tribe or of a prehistoric people. Some implements were found and evidences of the use of fire employed, perhaps, for the purpose of breaking up the rock. Another important locality is in Mineral Park, Mohave County. During the last two or three years this district has produced considerable material for the market. Several mining companies are operating in the district, among which may be mentioned the Arizona Turquoise Co., Los Angeles Gem Co., Southwest Turquoise Co., and the Aztec Turquoise Co. The deposit is found in certain hills along the west side of the Cerbat range of mountains, consisting chiefly of gneisses and schists cut by later granites and porphyries. Is is in these latter porphyries that the gem material is found. The porphyry is greatly decomposed in the vicinity of the turquoise. It would appear that some of the turquoise has been formed directly from the kaolinized material by the addition of copper and phosphated material. Gradations are observed between simply copper stained kaolin to

pure turquoise. An interesting specimen was recently cut by the Los Angeles Co., which consisted of the letter Y in blue in a gray matrix. It was formed by the intersection of two small veinlets. The stone was sent to a student at Yale.[1]

Nitre, KNO_3

This well-known compound is frequently formed on old wall, in caves, and on the side of mine shafts, usually however, in such small quantities as to escape observation. It is even said to develop in old morters to the extent of 5 per cent.[2] The writer has observed it associated with sodium carbonate as a thin white covering on the surfaces of the overhanging limestone shelves in the ancient cliff-dwellings of Walnut Cañon, about twelve miles from Flagstaff. The walls of the cañon here are made up of layers of soft and hard limestone, or more appropriately calcareous sandstone, which has disintegrated, yielding a series of shelves that have been very conveniently utilized as dwellings by the ancient inhabitants of Arizona.

Nitrocalcite

This is a hydrous nitrate of calcium sometimes met with in limestone caves, where doubtless an interaction has taken place between the calcium carbonate and bat guano or other organic compounds. A bacteriological action may also be concerned in its formation more or less direct from the atmosphere. It has been reported

[1] Mineral Resources, 1908.
[2] Dana: System of Mineralogy.

as occurring in the Mammoth Cave in Kentucky. A sample of this mineral mixed with a large quantity of earth was received at the University of Arizona during the summer of 1907 and indentified as calcium nitrate by Dr. A. E. Vinson of the Agricultural Experiment Station. Correspondence with the sender of the sample brought the following interesting information: "The calcium nitrate occurs in vents in the Lower Carboniferous Limestone, fissures that cut across the bedding planes and are therefore perpendicular. There are several of these vents grouped close together exposed to full view in the railroad cut facing the Gila river about two miles above Winkelman. The face at this spot is a sheer wall about 100 feet high and the vents filled with the nitrate are visible from top to bottom. None of them are more than 6 to 8 inches wide and the nitrocalcite seems to be mixed with red iron."[1]

Gerhardite

This is a basic copper nitrate found as a coating of dull green color, on the cliffs in the Clifton-Morenci district. It is supposed to have been formed through the action of atmospheric water on copper salts.[2] It is also found in the Jerome district associated with cuprite and malachite. (Dana.) It is a very rare mineral and is never found except as thin coatings or stains on other minerals.

Colemanite, $Ca_2B_6O_{11} \cdot 5H_2O$

An extraordinary occurrence of this mineral has been

[1] Private communication from Mr. E. B. Zachn, Winkelman, Arizona.
[2] U. S. G. S., PP. No. 43.

reported by Morgan and Tallmon.[1] It is found associated with a tar-like substance in a fossil egg found in the placer deposits of the Gila River.

(4) SULPHATES

Thenardite, Na_2SO_4

This mineral is the sulphate of sodium and usually appears as a dull yellow substance soluble in water. It is found in large deposits in the Verde Valley, Yavapai Co., near Camp Verde, where, mixed with halite, it is said to have been used as a substitute for salt for cattle and horses. The deposit is several acres in extent and fifty or more feet in depth. It is very compact, mingled with clay, and associated with Mirabilite, halite and glauberite.[2]

Glauberite, Na_2SO_4, $CaSO_4$

This mineral resembles the one just described but differs from it in containing calcium sulphate in addition to sodium sulphate. As stated above it is found in the Verde Valley associated with other soluble sulphate and chlorides.

Barite, $BaSO_4$

Barite, or the sulphate of barium, is commonly known as heavy spar because of its high specific gravity. It occurs most often as a gangue mineral, accompanying such sulphides as galena, iron pyrite, etc. It is usually nearly white in color and quite soft. In the Silver Bell

[1] Am. Jour. Sci., 18, 363.

[2] W. P. Blake, Am. Jour. Sci., 3d series, 39, p. 44.

district, barite is found as lustrous white aggregates of crystals associated with blue cubes of fluospar. In the Quiotoa district it is found in large masses, which on disintegration, yield aggregates of disk or shell-like shapes. They closely resemble shells which have been cemented together. They are sometimes covered with drusy crystals of calcite, siderite, or other similar minerals. It has further been observed in white seams in blue limestone west of the Tucson range of mountains, in the properties south of the San Xavier Mission, associated with argentiferous galena, and, in fact, associated with a variety of minerals in many of the mines of the State.

Anglesite, $PbSO_4$

This is the sulphate of lead and represents the first stage in the alteration of galena by which cerussite is finally produced. It being an intermediate product, it is of rarer occurrence that the carbonate, cerussite. When pure it is white and transparent, but more often appears as massive varieties with yellow, gray or nearly black shades. Samples from the Castle Dome district have been described and analyzed by Professor Brush.[1] An interesting modification of this mineral came to the writer's notice several years ago. The specimen came from the Tombstone district and exhibited pseudomorphous structure after galena. The sample weighed several pounds and originally consisted evidently of an aggregate of cubic crystals. These have altered to the sulphate in successive stages, giving rise to an appearance that can

[1] Am. Jour. Sci, 3d series, 5, p. 421.

best be described as alligator-skin structure. The successive layers about the original galena granule varied in color from nearly white to dark gray. Small slabs sawed from this specimen present, when polished, a very pleasing and striking appearance.

Crocoite, $PbCrO_4$

Chromate of lead is of rather rare occurrence in nature. It appears as bright red crystals and incrustations very much resembling vanadinite, but tetragonal in crystallization. It is found in the Vulture district associated with wulfenite and vanadinite. As shown by qualitative tests, it seems to be quite frequently mixed, isomorphously perhaps, with wulfenite, and in fact may be the cause of the deep color of many specimens. Samples from the Mammoth mine in the Catalina mountains seem to show a specially large amount of chromium.

Vauquelinite

This very rare phospho-chromate of lead has been reported from the Vulture district, where it is associated with crocoite and other lead minerals.

Spangolite

This is a basic sulphate of copper and alumina with some chlorine. It is found in very small quantities in the Metcalf mine of the Clifton-Morenci district in the form of bluish flakes and hexagonal incrustations in sericitized granite-porphyry, associated with cuprite, brochantite and chrysocolla.[1] It has also been reported from the Tombstone district.

[1] Lindgren: U. S. G. S., PP. No. 43.

Connellite

This is a rare chlor-sulphate of copper of very complex composition originally occurring at Cornwall. It has recently been discovered in Arizona in the Calumet and Arizona mine in Bisbee. It is described as associated with melanochalcite and chalcophyllite. It was found as dark blue radiating crystals the largest of which was 0.5 millimeters in length. The mineral was analyzed with the following results:[1]

	Per cent.
SO_3	3.43
Cl	6.37
CuO	75.95
H_2O	15.07
Less O = Cl	1.42
Total	100.40

Brochantite, $CuSO_4$, $3Cu(OH)_2$

Many of the green pulverulent minerals of copper, abundant in the mines of northern Mexico and Arizona and usually classified by the miners as malachite, have recently been proved to be the basic sulphate of copper or brochantite. Mr. Fred Hawley, a student in the University of Arizona together with the writer has investigated the chemical and mineralogical composition of these ores from the Cananea (Mexico) mines and found that they correspond quite close to the required formula. Mr. Hawleys analytical results were as follows:

[1] Palache and Merwin: Am. Jour. Sci 28, p. 537.

CuO	59.00
SO_3	17.40
H_2O	10.70
Al_2O_3	7.20
FeO and CaO	Traces
SiO_2	5.70

The alumina and silica are doubtless due to admixtures of kaolin, a mineral with which this compound is frequently associated.

Mr. Lindgren has noted brochantite in quite large quantities, associated with malachite, in the Clifton-Morenci district, and Mr. Ransome in the Copper Queen mines at Bisbee.[1]

Leadhillite, $2PbSO_4$, H_2CO_3

A rare carbono-sulphate of lead closely resembling cerussite occurring at Schulz, Pinal Co. (Dana's Text-book.)

Mirabilite, Na_2SO_4, $10H_2O$

This is a soluble sulphate of soda found in the Verde Valley, associated with thenardite and other soluble minerals. It seems to overlie the deposit and penetrate it in the form of veinlets.[2] It has also been observed as a white incrustation in the basalt caves near Sunset Peak, about fifteen miles from Flagstaff. (See Ice Caves.)

Gypsum, $CaSO_4$, $2\ H_2O$

Gypsum is a very common mineral and, when favorably located, is of commercial value in the manufacture of plasters. When burned at proper temperatures it develops the property of combining again with water and forming

[1] U. S. G. S., PP. Nos. 21 and 43.

[2] W. P. Blake: Am. Jour. Sci., 3d series, 39, p. 44.

a hard compact mass. This property is called "setting' and the raw burned material as well as the final product is well-known as "plaster of Paris". Gypsum occurs in nature in three well-known varieties: the fine grained white modification or alabaster, the transparent variety which easily breaks up into thin plates, or selenite, and the fibrous variety or satin spar. Gypsum is slightly soluble in water and since it results in the disintegration of nearly all rocks, through the oxidation of sulphides and interaction with calcium compounds, it is always found, in greater or less quantities, in natural waters. In arid regions like Arizona it is apt to be present in unusually large proportions. Where circulating water is not sufficiently abundant to carry the material away, it is deposited as a crystallized mineral in the form of impure gypsum. It is consequently very frequently met with in mines where sulphides are oxidizing and reacting with limestone, and where underground water is scarce. Although abundant oxidation has taken place in the Bisbee district, gypsum is entirely absent there because of the transporting action of large volumes of underground water.[1] In the Clifton-Morenci district where underground waters are less abundant it is of more common occurrence.[2] These deposits, of course, are not of sufficient size to be of commercial value, but are interesting from the fact that they throw light upon the chemical reactions taking place in connection with the deposition of the ore bodies. Deposits of commercial value are formed

[1] Ransome: U. S. G. S., PP. No. 21.

[2] Lindgren: U. S. G. S., PP. No. 43.

through the evaporation of a lake, pond or arm of the sea. These beds are therefore frequently depositories of common salt, and other soluble minerals. Hence it is found in the Verde Valley associated with thenardite, glauberite and allied minerals. Other places where it has been locally used for the manufacture of plaster, are the low hills along the San Pedro valley, in Fort Apache Reservation, Navajo County, in the Tucson Valley, and near Woodruff and Snowflake in the northern part of the State.

Epsomite, $MgSO_4$, $7H_2O$

As the name indicates this mineral is the natural Epsom salt or magnesium sulphate. It has been observed as delicate moss-like efflorescences on the walls of old tunnels in the mines of the Clifton-Morenci district.[1]

Goslarite, $ZnSO_4$, $7H_2O$

This is the soluble sulphate of zinc. It has been observed in the Clifton-Morenci district in exactly the same mode of occurrence as epsomite just described. It results from the oxidation of zinc sulphide and being soluble is transported and deposited by the evaporation of percolating water.

Linarite, $(Pb,Cu)SO_4$, $(Pb,Cu)(OH)_2$

This beautiful and rare mineral is found in the Mammoth-Collins mine at Schulz, Pinal Co., associated with cerussite, wulfenite and other lead minerals. It is deep blue in color and when mingled with pure white cerussite which is also of adamantine luster, presents an ap-

[1] U. S. G. S., PP. No. 43, p. 121.

pearance of unusual beauty. The crystallization is monoclinic, but only one crystal perfect enough to measure on the reflecting goniometer has been found. The following faces were indentified : — a, (100), c, ($\bar{1}$01), s, (001), y, ($\bar{2}$01), u, (101), w, ($\bar{2}$12), m, (110), and r, ($\bar{1}$11).

Chalcantite, $CuSO_4$, $5H_2O$

This is the well-known blue vitriol or blue stone. As a mineral it is frequently met with in copper mines, especially in old workings, where it is frequently found in incrustations on old timbers and the sides of the tunnels, as well as in the form of stalactites hanging from the roofs of cavities and workings. In some of the old tunnels of the mines in the Clifton-Morenci district it is reported as almost filling the opening with stalactitic masses.[1] In the Jerome district this mode of occurrence is very common ; indeed, the mine waters are especially charged with the mineral, so that it is found worth while to extract the copper by passing the water containing this mineral in solution, over scrap iron. Fine stalactites, received from this locality, were nearly two feet in length. Unfortunately the mineral does not keep well, and the loss of water of crystallization causes it to disintegrate and fall to pieces.

Copiatite, $2Fe_2O_3$, $5SO_4$, $18H_2O$

This is an unusually rare basic sulphate of iron. A small specimen from the Mineral Hill district has been identified at the University of Arizona. It appears as

[1] U. S. G. S., PP. No. 43.

small bright yellow, silky fibers, and slightly foliated masses, not unlike orpiment in general appearance.

Alunite, $K_2O, 3Al_2O_3, 4SO_3, 6H_2O$

This mineral is sometimes known as alum stone. It has been reported as occurring in a narrow seam on a contact between shale and porphyry in the Ryerson mine at Morenci. It is further sometimes found associated with pyrite and kaolin in other parts of the same district. It is described as sometimes quite clayey in appearance so that it might easily be mistaken for that mineral.[1]

Jarosite

This is usually a ocher-yellow, soft mineral having the composition of the hydrous sulphate of iron and potash. It has been reported from the Vulture mine where it occurs associated with gold in quartz.[2]

Emmonsite

The composition of this mineral is rather obscure, but it is thought to be a tellurate of iron with water. It has been reported from Tombstone as occurring it thin yellowish green scales.[3]

Ettringite

This is a hydrous sulphate of aluminium and calcium. It is of very rare occurrence. The mineral, however, has been discovered in the Lucky Cuss mine at Tombstone by Mr. W. F. Stanton and described and analyzed by A. J. Moses. It is a white fibrous mineral incrusting a silicate of lime and alumina.[4]

[1] U. S. G. S., PP. No. 43.
[2] Am. Jour. Sci., 3d series, 21, p. 160.
[3] Dana: Text-Book.
[4] Am. Jour. Sci., 3d series, 45, p. 489.

(5) TUNGSTATES, MOLYBDATES

Wolframite, $(Fe, Mn)WO_4$, and Huebnerite, $MnWO_4$

These rare and useful minerals have been reported from several localities in Arizona. The two minerals resemble each other so closely and gradate one into the other in such a manner that they can be distinguished only with difficulty without a chemical analysis. The huebnerite, however, usually shows a peculiar internal red reflection by which it can sometimes be distinguished. The two minerals are of equal value in the steel industries. Wolframite was first discovered in Arizona in 1896 by Professor W. P. Blake, then Director of the Arizona School of Mines. It was described as occurring in grains in quartz and associated with gold in the Arivaca district.[1] Perhaps the most extensively worked deposits are those of the Dragoon mountains near the Southern Pacific railway station of Dragoon Summits. The mineral from this locality was identified at the Arizona School of mines in 1898 as huebnerite and analyses made by the writer. The composition is represented in the following table:

FeO	2.66
WO_3	75.36
MnO	19.50
SiO_2	1.70
Undetermined	0.78
	100.00

The mineral occurs in extensive quartz veins, perhaps of pegmatitic origin, associated with small quantities of

[1] Eng. Min. Jour., 65, p. 607.

fluospar and scheelite. The excavation of the vein material is said to be unremunerative; gathering the float from the cañons and washes seem to be more profitable. Several car-loads of this material were received at the University of Arizona from the owners, Messrs. Stein and Boericke, for the purpose of concentration in the jigs of the School of Mines. The concentrates contained nearly 70 per cent. of tungstic acid, while the tailings assayed but 0.80 per cent. The price of the material thus concentrated has varied greatly according to the demand; the value has fluctuated from $80.00 to over $400.00 per ton.

Another tungsten locality has recently been opened up about 80 miles from Kingman, in the Aquerra range. The mineral is said to occur in grains and in masses weighing as much as twenty pounds.[1]

Still more recently the mineral has been found in the Whetstone mountains, about 12 miles south of Benson. This deposit is unlike any others of this mineral yet described. "The deposit is at the base of a steep rise in granite, which is intrusive in a series of metamorphic rocks, including siliceous mica, schist and limestone. The wolframite occurs near the contact of the granite and schist and in a tongue of granite 60 to 70 feet long and perhaps half as wide which runs out into the schist. The granite is very light colored, and except in segregations, contains no dark constituents. A little wolframite is found in the quartz vein, accompanied by small amounts of mica, bornite and probably chalcopyrite. A more

[1] Mineral Resources, 1905.

noteworthy quantity of wolframite occurs as segregations in the granite."[1] In places the material is said to average 10 per cent. tungstic acid, the source being segregations in the granite very much as biotite and hornblende are sometimes collected in irregular patches. The mineral, however, should not be looked upon as an original constituent of granite, but as the result of pegmatitic action. Samples from this locality have been analyzed in the laboratory of the University of Arizona, by Mr. J. M. Ruthrauff. His results are given in the table below.

	Per cent.
FeO	5.15
WO_3	74.20
MnO	18.09
SiO_2	1.95
Total	99.39

Deposits are further found in Sonora, Mexico, so it would seem that the zone in which the mineral occurs is of considerable extent.

Scheelite, $CaWO_4$

This is the calcium tungstate and occurs as a very heavy light yellow or amber colored mineral in the same kinds of formation as wolframite. As mentioned above it is found in small grains associated with wolframite in the Dragoon mountains. It is further found as a microscopic border about the wolframite grains in the whetstone mountains.[2] It is also found in the Old Hat district in

[1] U. S. G. S., Bul. No. 380, p. 164.
[2] U. S. G. S., Bul. No. 380.

the Catalina mountains, where it is described as occurring in friable masses of light brown.[1]

Wulfenite, $PbMoO_4$

Chemically this mineral is the molybdate of lead. It is usually found in thin tabular tetragonal crystals varying in color from nearly colorless to deep red or orange. In Arizona the deep orange varieties are, perhaps, the most common. The mineral is found as incrustations, implanted crystals and as massive modifications sometimes filling, together with considerable siliceous matter, rather large veinlets. It is almost always associated with vanadinite and other minerals of lead and vanadium. It is abundant in the Castle Dome district, the Mammoth mine near Oracle, the Old Yuma mine in the Tucson mountains and many other localities where it is nearly always found in quartz veins associated with gold or silver ores. Interesting samples of this mineral have been received at the University consisting of very intimate association of quartz and wulfenite. The sections for microscopic study have been made of these, and in nearly all cases it has been found that the silica fills up the interstices between the crystals of wulfenite showing that the silicification took place later than the deposition of the molybdate.

Molybdite

Molybdite, or as it is sometimes called, molybdic ocher, is a pulverulent yellow mineral, occurring as incrustations and tufts of small fibers in minute cavities and cracks in

[1] W. P. Blake: Rep. to Gov., 1909.

the vein material. Its intimate association with molybdenite or the sulphide, shows without much doubt that it has resulted from the latter through oxidation and other chemical changes. Until recently it has been considered as the trioxide of molybdenum, but the investigations of Mr. Schaller[1] has shown it to be a hydrated ferric molybdate. Investigations carried on in the University of Arizona further show that the Arizona specimens are also a ferric molybdate instead of the oxide.[2] In Arizona the mineral is found in white milky quartz, associated with molybdenite and limonite in the Santa Rita mountains. The composition was found on chemical analysis to be as follows:

Water	17.35
Fe_2O_3	21.83
MoO_3	60.80

These figures resulted after deducting the insoluble residue, which consisted of pure quartz, and recalculating the analysis. The formula deduced from the above figures is $Fe_2(MoO_4)_3 7H_2O$. Mr. Schaller's results give 7½ molecules of water of crystallization.

[1] Am. Jour. Sci., 4th series, 23, 297.

[2] Guild: Am. Jour. Sci., 4th series, 23, 455.

VII. NEW MINERALS DISCOVERED IN ARIZONA

Coronadite

This is a new mineral recently discovered by Dr. Hillebrand. Analysis by Dr. Hillebrand show it to be a manganite of lead. It contains 56.13 per cent. of manganese dioxide and 26.48 per cent. of lead oxide. It is described as a dark metallic mineral of fibrous structure and altering to limonite. It is very similar to psilomelane in appearance. It was discovered in the Coronado vein in the Clifton-Morenci district, and at present is the only known locality.[1]

Morencite

This is another new mineral recently discovered in the Morenci mines. It is described as a brownish yellow silky fibrous compound probably resulting from contact conditions in lime shale. The mineral has been analyzed by Dr. Hillebrand with the following results:[2]

	Per cen
SiO_2	45.74
Al_2O_3	1.98
Fe_2O_3	29.68
FeO	0.83
CaO	1.61
MgO	3.99
K_2O	0.20
Na_2O	0.10
H_2O, 105	8.84
H_2O, 150	0.12
H_2O Below redness	4.27
FeS_2	0.66
P_2O_5	0.18

[1] U. S. G. S., PP. No. 43.

[2] U. S. G. S., PP. No. 43, p. 115.

Copper Pitch Ore

This is an ill defined dark brown to black pitchy appearing mineral of copper, found associated with cuprite, chrysocolla, and other minerals of copper in the Copper Queen, Morenci and Globe districts. The mineral has been investigated from time to time but not very conclusive results as to its real nature have been reached. Perhaps the most satisfactory investigations are those of Lindgren and Hillebrand on samples from Clifton. Hillebrand's analysis gave the following results:

	Per cent.
CuO	28.6
ZnO	8.4
MnO_2	21.2
Fe,Al and P	4.0
Insoluble	22.8
Ignition	13.7

From the above preliminary analysis of Dr. Hillebrand the mineral would seem to be some compound of manganese and copper.[1]

Quite probably, however, this pitch mineral does not always have the same composition. Professor Koenig had examined some of the same or similar material from Bisbee. As the results of his analysis he considers the mineral to be a basic salt of orthosilico-carbonic acid. He has named the mineral Melanochalcite.[2]

[1] U. S. G. S., PP. No. 43, p. 114.

[2] Am. Jour. Sci., 14, p. 404.

Arizonite

This is a ferric metatitanite and has very recently been discovered on the claims of Mr. A. G. Alm, 25 miles from Hackberry, Arizona. It is associated with Gadolinite. Mr. Palmer found the composition to be as follows:[1]

	Per cent.
FeO	0.70
Fe_2O_3	38.38
TiO_2	58.26
H_2O	0.18
H_2O, 115	1.02

[1] Palmer: Am. Jour. Sci. 28, p. 353.

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